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Macroeconomic Indicators of Sustainability for Alberta

by

Angela Mary Pearson ©

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Macroeconomic Indicators of Sustainability for Alberta submitted by Angela Mary Pearson in partial fulfillment of the requirements for the degree of Master of Science in Agricultural and Resource Economics.

ABSTRACT

This research addresses the problem of measuring sustainable development. Two macroeconomic indicators of sustainability are assessed and empirically implemented for the province of Alberta. The first of these is environmentally-adjusted GDP (EDP), a measure of sustainable income. The second is the Pearce-Atkinson measure (PAM) of weak sustainability. The main focus of this study is Alberta's forest sector. Because of its importance to Alberta's economy, the energy sector is also included. Consequently, the adjustments made to construct the indicators in this thesis are for depletion of forest and energy resources.

EDP indicates sustainability in both the forest and energy sectors, and for Alberta, although it shows less growth than GDP in all cases. PAM indicates that investment, as measured conventionally, is not sufficient to offset disinvestment in natural capital. Whether or not Alberta's productive capacity has decreased also depends on considerations of human capital growth and technological change.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The issue of sustainable development became prominent with the publication of the Brundtland Report of the World Commission on Environment and Development. Subsequently, it became a focal point for international consensus at the United Nations Conference on Environment and Development (i.e. the Earth Summit), in 1992. Since then, many national governments have taken steps to develop sustainable development strategies.

These initiatives have inevitably brought into focus the problem of defining sustainable development. In the Brundtland Report, sustainable development was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development [WCED], 1987). This highlights issues of future quality of life, as well as issues of the carrying capacity of the world's life support systems. Many other definitions of sustainability have been put forward. Most point to the need to simultaneously address economic, environmental and sociopolitical objectives.

The debate on sustainable development has moved forward from the problem of defining sustainability to problems of measurement. It is necessary to assess whether or not a given economy is using its natural resource base in such a way as to significantly disadvantage future

generations. The concept of sustainability is very broad, as noted above, and has a range of underlying ethical implications. Consequently, it presents a difficult measurement problem. This underlies the need for indicators of sustainabiity. The function of an indicator is to provide a succinct representation of a complex system, without unduly compromising accuracy. Different research disciplines have brought very different sets of priorities to this problem. Moffatt, Hanley, and Gill (1994) have identified three main classes of indicators of sustainble development: economic, ecological and sociopolitical.

Of these disciplines, economics already has a fairly well articulated indicator framework, the UN system of national accounts (SNA). Environmental adjustments to these conventional accounts comprise a major strand of economic research on sustainability indicators. Adjustments to conventional accounts are made by placing monetary values on environmental services. The stocks and flows of natural resources and environmental assets are measured, in monetary terms, and incorporated into the national accounts. Thus sustainability is measured by quantifying the impacts of economic activity on the environment, and adjusting the economic accounts accordingly. In this thesis, conventional economic accounts are adjusted for the value of natural resource depletion by Alberta's forestry and energy industries. Adjustments are not made for environmental degradation or for non-market values.

1.2 RESEARCH OBJECTIVES

The central objective of this thesis is to assess the sustainability of Alberta's forest industry. Because of its importance to Alberta's economy,

and to provide perspective on the forest sector, Alberta's energy industry is also evaluated. Income adjustments, as described in the previous paragraph, are made for both sectors, and for the entire Alberta economy. The adjustments made are not complete, but constitute the first steps necessary to quantify sustainable income for these two sectors, and for Alberta.

This thesis also implements a test of weak sustainability, the Pearce-Atkinson measure (PAM). This is closely related to the income adjustments described above. In the case of PAM, adjustments for impacts on the natural resource base (specifically, forest and energy resources) are made to conventional measures of flows of capital for Alberta. Thus sustainability is evaluated on the basis of whether the total capital stock is increasing or decreasing. Capital stock, in this context, is defined broadly, to include both natural and man-made capital.

A further objective of this thesis is to provide a survey of existing research on measurement of sustainable development, as outlined below.

1.3 OUTLINE OF THE THESIS

This survey starts with some of the more operational definitions of sustainability. These are outlined in Chapter 2. Different types of capital and levels of sustainability are defined in Chapter 3. As well, the approaches of economics and ecology to the problem of measuring sustainability are compared in Chapter 3. Some important rules for achieving sustainability have evolved from the economic approach: these are described in Chapter 4. Chapter 5 introduces various types of

indicators. A range of indicator types that have been applied to sustainability is described, and the two indicators implemented in this thesis are compared to some others.

In Chapter 6, the rationale behind the sustainable income (EDP) and PAM indicators is presented. In Chapter 7, the data used in the implementation of these indicators are described. Chapter 8 presents the empirical results, and interpretation of EDP and PAM as measured for Alberta's forest and energy sectors. Final conclusions from this analysis are presented in Chapter 9.

CHAPTER 2: DEFINITIONS OF SUSTAINABILITY

2.1 INTRODUCTION

A widely accepted definition of sustainability is that provided by the Brundtland Commission: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (World Commission on Environment and Development [WCED], 1987). This is intended to highlight two key concepts. The first of these is the concept of 'needs', particularly those of the world's poor. The second is that of limitations on the ability of the environment to support the needs of both present and future generations, imposed by the states of technology and of social organisation (WCED, 1987).

The goal of sustainable development requires that equity be attained both within generations (intragenerational equity) and between generations (intergenerational equity). The themes of inter- and intragenerational equity are common to many definitions of sustainable development (Hanley, 1996; Hanley, Shogren, & White, 1996). Most definitions also imply that per capita wealth, broadly defined, should not decrease over time (World Bank, 1995).

It is now widely accepted among environmental economists that sustainable development is largely a matter of intergenerational and intragenerational equity, as well as efficiency (Howarth & Norgaard, as cited in Hanley, Shogren, & White, 1996). Efficiency, in the conventional economic sense, is relevant to sustainable development in that demands

on the environment are reduced if a given amount of human well-being can be produced from fewer natural resources. However, as will be discussed below, economic efficiency is not enough to ensure sustainable development. Trade-offs must be made between sustainability and efficiency (Hanley, Shogren, & White, 1996).

2.2 DEFINITIONS

Even among the definitions of sustainability developed by economists, there is considerable variation. These have been categorised by Hanley (1996) as those defined in terms of ends, and those defined in terms of means.

Sustainable development was implicitly treated as non-declining consumption over time (an 'end' of sustainability) in early work incorporating natural resource constraints in neoclassical growth theory (Hartwick, 1977; Solow, 1974). This work focused on intergenerational efficiency rather than equity. The Hartwick rule, discussed below, emerged from this literature. Non-declining consumption has given way to non-declining utility as a policy goal in economic models (Pezzey, as cited in Hanley, Shogren, & White, 1996). This reflects the recognition that utility is derived directly from the environment, as well as from the consumer goods for which natural resources are inputs.

Ends-based definitions of sustainability also include those based on utility. Current economic definitions tend to focus on non-declining per-capita human well-being over time (Pearce, Barbier, & Markandya, 1990).

Similarly, Dasgupta (1995) has stated that the focus of concern should be present and future well-being.

Alternatively, sustainable development has been defined in terms of the means of producing utility. Several authors have identified a relationship between non-declining utility or well-being, and the underlying capital stock (Pearce & Atkinson, 1995). In this vein, Hartwick (1977) has examined non-declining total capital stock (i.e. natural and man-made capital) as the key condition for sustainable development. In an extension of this, Pearce, Barbier, and Markandya (1990), have summarised the main necessary condition for sustainable development as “constancy of the natural capital stock”.

Bishop and Woodward (1994) have argued that sustainability should not be defined in terms of utility levels, since the relative levels of utility of respective generations can be distorted by intragenerational inefficiencies. For example, if the current generation fails to use resources efficiently, it will leave to future generations a potential level of utility that is lower than it might have been, even if it is higher than that of the present generation. These authors state that, for this reason, sustainability should be defined in terms of endowments, in essentially the manner of Hartwick (1977), above. The endowments, broadly defined, that are passed from one generation to the next must be sufficient to allow non-decreasing utility possibilities.

The diversity of the definitions above reflects what Robert Solow (1991) has referred to as the “intrinsically inexact” nature of the concept of sustainability. Notwithstanding the vagueness of the concept, the definitions point to a variety of issues. For example, the WCED definition presented above points to the need to simultaneously address

developmental and environmental imperatives. However, it also raises some difficult operational questions. In particular, the meaning of “needs” is relatively obvious for the world’s poor, but it is much less obvious in the context of communities that are already affluent. People in the second category presently consume more than 80% of the world’s income (Serageldin, 1996).

2.2.1 Operationalising Sustainable Development

What, then, are the operational implications of the concept of sustainable development? The World Bank’s recent work in this area has selected key conceptual issues which promise to have important operational implications (Serageldin, 1994). World Bank work on the development of an operational definition of sustainable development has focused on expansion of capital stock as a key idea in dealing with sustainability questions. Thus, in this approach, wealth, as commonly identified in definitions of sustainable development, is implicitly equated to the economic concept of capital, and to the general concept of opportunity. Hence the following emerges as an operational definition of sustainability: “Sustainability is to leave future generations as many opportunities as we ourselves have had, if not more” (Serageldin, 1996, p.3).

In this approach, the economic concept of capital is used as a measure of opportunity. Maintaining capital intact is an issue central to all economic behaviour and analysis (El Serafy, 1989). Nobel laureate Sir John Hicks paraphrased this principle into a definition of income, as “the maximum value a person can consume during a week, and still expect to be as well off at the end of the week as at the beginning.” (as cited in Serageldin, 1996, pp.3-4). Where capital is depleted, one does not

consider the proceeds to be an income stream. Income based on depletion of capital is not sustainable, and should not be thought of as income. Capital and its growth are the means by which it is possible to provide opportunities for future generations (Serageldin, 1996).

This approach leads to a relatively accessible means of operationalising sustainability, by measurement of capital stock. Notwithstanding some disagreement as to the proper economic interpretation of sustainable development, a consensus has emerged that it relates closely to the concepts of capital and income (Statistics Canada, 1997). Consumption should be limited to an amount that will not lead to depletion of capital. The World Bank's operational definition of sustainability, above, is in line with this consensus.

CHAPTER 3: APPROACHES TO SUSTAINABILITY

3.1 INTRODUCTION

Increasing concerns over sustainability are extending the range of issues that must be considered in the assessment of the potential impacts of proposed projects. Munasinghe (1993) identifies three distinct concepts of sustainable development which must be reconciled and operationalised within the economic framework. These are concepts of sustainable development based on economic, ecological, and socio-cultural criteria.

3.2 TYPES OF CAPITAL

Since the concept of capital stock is, as identified above, central to sustainability issues, it is necessary to define what is and is not encompassed by the term 'capital'. Four distinct forms of capital, somewhat parallel to Munasinghe's three concepts of sustainable development, are commonly recognised in broad-based discussions of sustainability.

1. Man-made capital is capital as it has been conventionally defined in the economic literature. This includes all man-made means of production (Black, 1997), such as tools, machinery, plants and buildings. Man-made capital has also been defined as assets capable of producing a flow of income, and which have themselves been produced (Bannock, Baxter, & Davis, 1992). This focuses on the significance of capital as deferred consumption: all man-made capital is itself produced from raw materials and labour, and may be considered to hold the stored value of

raw materials and labour. This characteristic of man-made capital has implications for its role in defining and promoting sustainability which will be discussed below.

2. Natural capital may be defined as the stock of environmental and resource assets, including mineral ores, soil, forests, water and air, which generates a flow of useable goods and services (Serageldin, 1996). While most existing economic analysis treats the consumption of natural assets as income, all consumption based on the depletion of natural capital should be accounted for as reduction of the stock of natural capital.

   Until recently, natural capital has been regarded as being abundant in terms of the scale of human use. Most of economic theory still reflects an emphasis on man-made capital, which, historically, has been limitative (Daly, 1990; Serageldin, 1996). Natural capital has only recently begun to be accounted for, as environmental assets increasingly emerge as factors that limit production, both in their roles as sources of inputs and as sinks which must absorb waste materials.

3. Human capital formation identifies investment in people, and includes investments in education, health and nutrition (Serageldin, 1996). Investment in human resources has, in the last few decades, come to be recognised as yielding high returns, and as being particularly important in developing countries.

4. Social capital encompasses the ways in which economic agents organise themselves to promote growth and development. These combine with man-made, natural and human capital to determine

economic growth (Grootaert, 1997). Social capital thus includes those elements, based in common forms of social behaviour, that contribute cohesion to a well-functioning society (Serageldin, 1996).

A narrow concept of social capital is associated with Professor Robert D. Putnam (Putnam; Putnam, Leonardi, & Nanetti, as cited in Grootaert, 1997). Putnam has argued that the presence of strong civic community, characterised by voluntary horizontal associations (clubs, civic action groups), is important for the effective operation of government, and for sustained socio-economic development. Here, the important characteristic of social capital is that it promotes cooperation for the mutual benefit of the association's members (Grootaert, 1997; Serageldin, 1996). Broader concepts of social capital also extend to more formally structured institutions, such as governments and legal systems (Grootaert, 1997).

While the significance of social capital is widely accepted, consensus is lacking as to which aspects of interaction and organisation truly constitute social capital. Measurement of social capital, and of its contribution to economic growth and development, remains problematic. Further, its classification as a form of capital may not be entirely valid. Social capital enhances the efficiency of investment in other forms of capital: it is a shift factor in a production function, analogous to technology, rather than simply an input (Grootaert, 1997).

The World Bank (1995) has made preliminary estimates of man-made, natural and human capital across the world. This work points to the importance of wealth in the form of human capital, with natural resources (excluding life-support functions) also being more abundant than man-

made capital. Human resources were estimated to constitute from 36% (in developing countries exporting raw materials) to 67% (in high-income countries) of total wealth, the world-wide average being 64%. Natural capital was estimated to comprise 20% of wealth world-wide, and man-made capital 16%. Furthermore, this research has suggested that real growth rates are better explained by the development of human resources than by the accumulation of man-made capital (World Bank, 1995).

3.2.1 Types of Capital - Discussion

If the World Bank's definition of sustainability as opportunity based on capital (above) is adopted, we should provide future generations with as much capital per capita as we ourselves have (Serageldin, 1996). This is a definition which focuses on the importance of wealth (a stock), as opposed to income (a flow). However, the four forms of capital defined above are to some extent substitutes and to some extent complements. The capital we pass on to the next generation is likely to differ in composition, in terms of these four constituents, from that we use ourselves. Yet, no sustained activity would be possible in the absence of any of these four types of capital. Clearly, the degree of substitution that is possible between the four forms of capital has important implications. Our definition of sustainability must extend beyond the total amount of capital per capita that we leave to future generations. It must also be concerned with the four types of capital, both individually and in combination (Serageldin, 1996).

Different assumptions have been made as to the extent to which the four types of capital may be substituted. Does the requirement to leave to future generations opportunities equal to our own imply passing on the same quantity and composition of natural capital as we ourselves

received? Or is it equally acceptable to deplete some natural capital, for example, while investing in new human capital? Serageldin (1996) asserts that, by defining sustainability in terms of the combination of the four types of capital, and focusing on the opportunities arising therefrom, we imply a relatively promising concept of sustainability, where some substitution of the four types of capital is possible. It is, nevertheless, accepted that the four kinds of capital are, to some extent, complementary, and that critical thresholds for each form of capital must be respected.

The usefulness of the definition of sustainability as non-declining capital stock, including all four forms of capital, thus depends heavily on our ability to

- measure each kind of capital;
- define exchange rates between the different kinds of capital, while allowing that these exchange rates may be dynamic;
- define production functions as to the levels of substitution possible between the different kinds of capital, accepting that these may also be dynamic; and
- define the critical thresholds which constitute the biological and other limits within which economic activities can be carried out sustainably (Serageldin, 1996).

Clearly, such a definition of sustainability, based on the maintenance or increase of the four types of capital, is, at present, far from rigorous. Our ability to measure the different kinds of capital, and our understanding of the connections between them, must be improved (Serageldin, 1996). As Pearce and Atkinson (1993) have noted, the concept of natural capital does not adequately represent the interface between economy and environment:

it does, however, provide a framework which allows considerable progress toward accounting for environmental problems.

3.3 LEVELS OF SUSTAINABILITY

Serageldin and Steer (1994) have defined four distinct levels of sustainability, based on different assumptions as to the extent to which different forms of capital can be substituted.

1. Weak sustainability accepts the need to maintain the level of total capital, but not to maintain any particular composition. Here it is assumed that, at least at present levels of economic activity, and in the context of the present levels of resource stocks, the different kinds of capital are substitutes (Serageldin & Steer, 1994).

2. Sensible sustainability requires the maintenance of the level of total capital, and also that critical levels of each type of capital be maintained. Thus man-made and natural capital are assumed to be largely substitutes, but also, at some point, complementary, since the economy requires a mix of the different types of capital. Here, it is important to acknowledge that these critical levels, below which the economy cannot function efficiently, have not been identified. Some caution is therefore indicated in the depletion of resources (Serageldin & Steer, 1994).

3. Strong sustainability requires the maintenance of the levels of the sub-components of capital independently. Natural and man-made capital are assumed to usually be complements, not substitutes (Serageldin &

Steer, 1994). A strong sustainability rule requires that natural capital increase or remain constant, while total capital is also required to increase or remain constant (Pearce & Atkinson, 1995).

A somewhat different concept of sustainability also often falls under the title of "strong sustainability". This alternative strong sustainability rule requires that critical natural capital be non-decreasing. Here, it is recognised that the various components of natural capital may not be perfect substitutes. Critical natural capital includes those components of natural capital that are essential for the provision of critical ecosystem functions. This kind of sustainability rule would provide for the maintenance of rare or endangered species, or unique natural phenomena. Under such a rule, the possibility remains of substitution between non-critical natural capital and man-made capital (Pearce & Atkinson, 1995).

4. Serageldin and Steer (1994) also identify <u>absurdly strong sustainability</u>, where the assumption is that nothing should be depleted. Non-renewable resources could not be used at all, and only net growth could be harvested from renewable resources.

The four definitions above serve to illustrate a continuum of economic interpretations of sustainable development. The issues of substitution and complementarity raised in these definitions must be confronted in any attempt to measure sustainability. The terms weak and strong sustainability, representing the opposite ends of the spectrum, are the ones commonly used in discussions of sustainability.

3.3.1 Sustainability Levels - Discussion

Robert Solow (1991) points out the limitations of the argument that different forms of capital cannot be substituted. Solow argues that efforts to preserve in detail the world as we have found it constitute a fundamentally incorrect approach to sustainability issues. This approach is not only infeasible, but also, arguably, undesirable. It would require that no mineral resources be exploited, and that no permanent construction be carried out. This implies constraints on development beyond what would be widely accepted. Solow therefore argues for a definition of sustainability which allows for permanent changes to the environment, provided that people in the future are left the capacity to be as well off as we are. This is very similar to the World Bank's operational definition of sustainability, above.

Conversely, Daly (1990) points out the shortcomings of the argument that unlimited substitution is possible between the different forms of capital. Daly's argument is that man-made and natural capital are essentially complements, not substitutes, in production. Production involves the transformation of natural resources and energy by man-made capital and labour. The functions of man-made capital and labour, as agents of transformation, are qualitatively similar, and these two are largely substitutable. On the other hand, natural resources constitute a flow of material which is transformed in production, and as such they are qualitatively very different. Man-made capital and resources, agent of transformation and that being transformed, are overwhelmingly complements. Man-made capital can only substitute for resources in the marginal sense of improved equipment which can utilise resources more efficiently. Daly argues further that, while man-made capital has limited

production in the past, we are now entering a time when production will increasingly be limited by natural capital.

Again, the questions of the true extent of substitution between natural and man-made capital, and of the ways in which the two differ, are central. They will be discussed further in the later chapters of this thesis.

3.4 ECONOMIC AND ECOLOGICAL APPROACHES TO SUSTAINABILITY

Human activities have been identified as part of an open dynamic socio-economic subsystem which is embedded in the global ecosphere (Munasinghe, 1993). Locally and globally, the rapid growth of the socio-economic subsystem in recent times has started to overload some of the capabilities of the ecosystem. It has been argued that, given that the ecosphere is finite, material-intensive economic growth is not sustainable in the long run.

3.4.1 The Ecological Approach to Sustainability

The ecological view of sustainable development emphasises the stability of physical and biological systems (Munasinghe, 1993). Protection of biological diversity is a key aspect, and the viability of those subsystems that are crucial to the overall stability of the global ecosystem is also of particular importance. This approach focuses on the preservation of the resilience and dynamic ability of natural systems to adapt to change. Here, "natural" systems may be interpreted as including man-made environments, as well as other aspects of the biosphere.

Protection of biological diversity and preservation of the resilience of natural systems are objectives with much in common. This is largely because genetic variation, which is perhaps the most fundamental dimension of biodiversity (Kimmins, 1991), is a major determinant of the ability of a species population to adapt to changes in its environment (Ayala, 1978). Consequently, conservation of species may involve conservation of the genetic variation in their populations as much as it involves conservation of their habitats. Furthermore, in the event of changes in climate and soil conditions caused by humans, preservation of genetic diversity will become increasingly important over time (Kimmins, 1991).

In British Columbia, the timber industry is clearcutting forests and substituting simplified, largely single-species plantations. Furthermore, plantation monocultures are increasingly based on the same genetic strain of a tree species. Herb Hammond (1991) argues that the simplification and loss of genetic diversity resulting from these practices result in the loss of the forests' ability to sustain themselves. Increased simplification of the forest brings with it increased vulnerability to natural hazards and to climatic change. Forest ecologist Chris Pielou notes that "Clearcutting causes two kinds of fundamental ecological damage, one long lasting, the other permanent. The long lasting damage is to the soil, the permanent damage is to biological (genetic) diversity" (as cited in Hammond, 1991, p. 127).

Hammond (1991) notes that many researchers believe that the decline in health of European forests is due to loss of the biological diversity necessary to maintain a fully functioning forest ecosystem. In

these cases, continuous cropping to maintain even timber flow has eroded biodiversity over time, resulting in tree plantations only capable of producing the projected sustained yield with increased technological inputs. Intensive sustained-yield timber management practices have typically stressed ecosystem structures and functions to the point where soil is degraded, water quality and quantity are reduced, and fish and wildlife populations are depleted. The overall level of biological diversity, which is required to sustain the forests, is lowered.

In the past, natural resources were not necessarily considered to be so limited in supply as to impose a significant limitation on growth. In line with the framework outlined by Munasinghe, above, Rees (1994) has identified three fundamental ecological principles which have come to pervade attitudes toward resource use more recently.

1. Human economic activity operates as a subsystem within a larger ecosystem. Disruption of the ecosystem (by resource depletion or pollution, for example) will ultimately interfere with the life-support systems supporting the economy.
2. With expanding economic activity, whereby growing human populations produce increasing amounts of waste, and consume increasing amounts of resources, the carrying capacities of ecosystems may be exceeded.
3. Some of the impacts of development have the potential to cause long-term, and possibly irreversible environmental changes.

Thus ecologists tend to bring a system-wide perspective and a long-term view to decision-making processes around environmental issues (Rees, 1994). The ecological approach to sustainability involves analysing the impacts of economic activities on biological systems (Rennings &

Wiggering, 1997). As noted above, it emphasises protection of the inherent abilities of ecosystems, such as ecological stability and resilience, so that the integrity of ecosystems is preserved. Prevention of environmental damage is thus a key theme in the ecologist's approach.

Environmental policies increasingly focus on anticipating and preventing major ecological impacts, rather than reacting to them after the fact (Rees, 1994). This is in response to the high costs that have been incurred by recovery of damaged ecosystems in the past. As policies assume an emphasis on anticipation and prevention, it can become necessary to take action before scientific proof or political acceptance of environmental damage is established. Ecologists are increasingly involved in the design and implementation of development projects. However, owing to these factors, predictions of environmental impacts are apt to be based on insufficient knowledge.

These are difficulties which confront ecologists in their efforts to measure and predict the impacts of development projects on natural systems. Environmental assessments (EAs) are emerging as a dominant method whereby ecologists identify the probable significant impacts of development on ecosystems in view of these obstacles. There remains a need for the application of EAs to be expanded to allow a more inclusive and integrated view. For example, environmental assessments should include evaluation of resource exploitation by a given project in terms of the needs of the entire region affected. EAs should also have the capacity to consider such functions as multiple use of natural resources, and integrated disposal and treatment of wastes. Such expansion of the scope of environmental assessments will facilitate the incorporation of ecological factors into economic decisionmaking (Rees, 1994).

3.4.2 The Economic Approach to Sustainability

Economic growth has, historically, been the main goal in the development of the industrial world. In recent decades, increasing pressure from social and environmental issues has necessitated that the model be broadened in scope. Policy makers are increasingly concerned with finding sustainable alternatives. The main goal has evolved from one of economic growth toward one of maximising the net welfare of economic activities, subject to maintenance of the stock of economic, environmental and sociocultural assets (Munasinghe, 1994).

Environmental economics enables us to move toward sustainability by providing a means of incorporating social and environmental objectives into economic decision making. It involves a synthesis of existing economic principles, and their extensions: the principles of economic optimisation and efficient allocation are applied to environmental and social objectives (Munasinghe, 1994).

Such an extension of these economic principles is the valuation of environmental impacts not normally reflected in market transactions. For example, externalities may be valued, and charges applied that will allow the market to compensate for them. Open access resources which tend to be overexploited may be valued, and corresponding charges applied for their use. Where possible, prices of inputs and outputs which are not properly priced by the market are adjusted, based on the economic opportunity costs of externalities (Munasinghe, 1994).

Environmental economics, then, is largely concerned with efficient pricing. As Rennings and Wiggering (1997) state of neoclassical economics, the avoidance of environmental problems is taken to depend largely on the efficient use of natural resources. Efficient resource allocation depends on getting prices right. As one means of achieving this, where external effects cause market failures which result in inefficient use of resources, external costs are estimated by various methods, and efforts are made to internalise them.

Some environmental objectives do not readily lend themselves to application of the concepts of economic optimisation and efficient allocation. For example, the loss of ecological resilience with respect to disturbances is not easily valued (Munasinghe, 1994). Generally, economic principles are more easily applied to the effects of resource depletion, particularly where mineral resources are concerned, than to the environmental impacts of pollution. The effects of pollution are more widely seen as being outside the control of the market system (Victor, 1991). Some environmental assets are essentially irreplaceable. Trade-offs between these and other forms of capital are not applicable in the same way as to more utilitarian resources, such as minerals (Solow, 1992).

The adjustment of national accounts to reflect environmental impacts is a further instrument, operating at the macroeconomic level, which tracks the effects of economic decisions (Munasinghe, 1994). In practice, measures of sustainable income are usually made by taking conventional measures of GNP as a starting point, and making two major adjustments (Pearce & Warford, 1993). First, GNP must be corrected for its own distortions regarding environmental capital. This involves deduction of restorative and, arguably, aversive expenditures for environmental

damage, residual pollution damage, and overstatements due to non-optimal use and depletion of natural resources. Secondly, NNP is calculated, by deduction of depreciation of both man-made and natural capital (Pearce & Warford, 1993).

As Solow (1992) has pointed out, these adjustments, if made correctly, can be equated to an optimisation process where investment and resource depletion decisions are made so as to maximise the sum of future utility. The process is constrained by the existing stocks of man-made capital and natural resources, and by technology. Thus, again, the concept of economic optimisation is extended to encompass environmental issues.

This optimisation leads to a requirement to reinvest the Hotelling rents from resource depletion or degradation. This, in turn, can also be interpreted as a requirement to maintain the capital stock intact. The level of consumption that can be sustained without reducing the capital stock corresponds, in turn, to Hicks' definition of income, presented above (Pearce & Atkinson, 1995; Solow, 1992). Thus the line of analysis which begun with utilising resources and investing so as to maximise utility over the long term, establishes the rule of maintaining constant capital stocks. This same rule was identified, above, with an operational definition of sustainability.

Hence, the extension of economic optimisation to include environmental issues, and to maximise welfare in a broader sense, largely defines the economic approach to sustainability. Substantial agreement exists among economists that sustainability is closely related to the Hicks-Lindahl concept of maximised generation of income, while the stock of capital from which these benefits flow is at least maintained (Munasinghe,

1993; Statistics Canada, 1997). The capital stock, now more broadly defined, must be maintained to ensure the sustainabilty of income, and intergenerational equity (Munasinghe, 1994). Most importantly, capital stock is now understood to include environmental assets as well as produced capital.

3.4.2.1 The Economic Approach - Shortcomings

It is acknowledged above that economic optimisation is more readily applicable to some environmental objectives than to others. Certain environmental assets hold intrinsic value: to the extent that these are irreplaceable, the trade-offs involved in optimisation are not appropriate (Solow, 1992). While the extraction of minerals, for example, may be fairly realistically represented in an economic framework, this is less true of some ecosystem functions.

The so-called “life-support” functions of ecosystems are examples of the environmental assets whose substitutability is most open to question (Pearce & Atkinson, 1995). Cycling of nutrients, and maintenance of a balance of carbon are ecosystem functions which illustrate the point. To date, economists have not effectively captured such functions; consequently, future losses in this area will tend to be underestimated.

A further difficulty differentiates environmental assets from marketable resources. This is the relatively high level of uncertainty surrounding environmental assets (Solow, 1992). Our understanding of the natural world is far from complete. For example, the exact ways in which carbon and nutrient cycles work are unknown.

Uncertainty also applies asymmetrically to natural and man-made capital (Pearce & Atkinson, 1995). Knowledge of the various elements of man-made capital is relatively complete. As well, reversibility differentiates natural and man-made capital. While the stock of man-made capital can be increased or decreased quite readily, recovery of lost natural assets is more likely to be infeasible, or technically impossible. Extinct species, for example, cannot be recreated.

Global environmental issues such as ozone depletion, biodiversity loss, and global warming are perhaps of particular note in the contexts of uncertainty and irreversibility. The environmental degradation resulting from these very pervasive problems has future impacts which are uncertain and possibly irreversible. A precautionary approach has often been endorsed with a view to limiting such impacts. This underlies, for example, the developing consensus to reduce emissions of greenhouse gases, with a view to limiting their possible irreversible effects on global climate (Munasinghe, 1994).

These factors contribute to the arguments against the feasibility of substituting man-made capital for natural capital. Pearce and Atkinson (1995) note that, while economic models tend to assume a high level of substitutability between the different forms of capital, empirical evidence for it has usually been based on narrow definitions of natural capital. Such definitions fail to recognise the full significance of natural capital in human welfare. It has been argued that this is illustrated by the endowment effect reflected in many contingent valuation studies.

The relationship between natural and reproducible capital remains the subject of much debate among economists. Clearly, the combination of

uncertainty and irreversibility governing the natural world argues that the composition of the capital stock we maintain is important. The ability of man-made capital to substitute for certain elements of natural capital remains in some doubt. As outlined above, in the discussion of levels of sustainability, it remains open to debate to what extent reproducible capital loses its value in the absence or scarcity of natural capital.

Economic models have mostly adopted assumptions of relatively unlimited substitution between man-made and natural capital. This allows the extension of economic optimisation to include natural capital in an economic framework. The remaining ambiguity in the matter of the substitutability of man-made and natural capital is often assumed away in the economic approach to sustainability. To the extent that these two classes of capital are in fact complementary, this assumption is a weakness in the economic approach to sustainability.

This point is illustrated in Dasgupta and Heal's (1979) major neoclassical text on resources. Their description of production technology at the aggregate level uses a Cobb-Douglas production function. This leads to the conclusion that, provided the elasticity of output for reproducible capital is greater than that for exhaustible resources, then the possibility exists for output to be maintained in spite of increasing resource scarcity (Victor, 1991). The flaw in the argument is that, where a Cobb-Douglas functional form is adopted, the elasticity of substitution between inputs is always unity. Consequently, by the assumptions inherent in this type of production function, further substitution of man-made capital for natural capital is always possible, even where availability of the resource is declining. Again, the extent to which man-made capital is assumed to be able to substitute for natural capital in the economic approach to

sustainability is open to question. The assumptions of the economic approach appear implausible where natural assets are recognised as having intrinsic value, or where a high degree of uncertainty surrounds environmental costs and benefits. A better representation of the interface between the economy and the environment is needed.

3.4.2.2 Efficiency vs. Sustainability

At the beginning of this section describing the economic approach to sustainability, it was identified that economists are generally concerned with improving market efficiency where natural resources and environmental assets are concerned. The economic approach was described as being concerned with counteracting market failures resulting from externalities, property rights failures, or the public good character of many environmental assets.

In recent years, the world's economy has grown rapidly with respect to the carrying capacity of the earth. Such environmental issues as global warming, ozone depletion, soil erosion, and biodiversity loss are reflections of this. Increasingly, it is argued that a broader framework than that of market efficiency is needed to address environmental problems.

Bishop and Woodward (1994), for example, state that, of the infinite number of efficient time paths open to an economy, many involve actions in the short term that will result in future generations being left with fewer economic opportunities than the present generation. These paths are efficient, but not sustainable. In defining and solving many of today's environmental problems, sustainability is an increasingly important goal. These problems need to be analysed in terms of both sustainability and

efficiency. More fundamental adjustments than improved efficiency may be required. Bishop and Woodward (1994) suggest that both goals, sustainability and efficiency, must be pursued. Thus society should seek to follow efficient time paths, with the additional constraint that only those efficient time paths that are also sustainable, are acceptable. Consistent with economic theory, this constraint is defined as a requirement that future generations have economic opportunities at least as great as those of earlier generations. In other words, the additional constraint is that the endowment passed on to each successive generation must be such as to allow opportunities at least equal to those of the current generation.

Having accepted the necessity of making sustainability a goal, difficulties in achieving this must be acknowledged. In particular, even if the people of the current generation have the will to enhance future opportunities, they are unlikely to be able to identify the best ways of doing so. For example, the endowments concerned include both environmental endowments and non-resource endowments. Environmental resources must generally be used by each generation seeking to enhance non-resource endowments. Consequently, complex trade-offs must be made. Clearly, it is impossible to judge, at each stage, what would be the best combination of environmental and non-resource endowments to pass on in order to most benefit the future, particularly the distant future. Each generation is largely ignorant as to how its use of its various natural resources will influence the economic opportunities open to subsequent generations (Bishop & Woodward, 1994).

Bishop and Woodward (1994) argue that this is an extreme form of uncertainty. Further, they question whether the usual procedure of assuming that outcomes and their associated payoffs are known, and that

probabilities are known at least in subjective terms, is applicable. In reality, some outcomes are unknown, and payoffs from known outcomes may be unclear. The important point is that the economic implications for future generations of alternative endowment vectors are extremely uncertain. Consequently, the sustainability constraint cannot be accurately identified in specific terms of endowments. Still less could it be reliably implemented (Bishop & Woodward, 1994).

Daly (1992) analyses this problem of uncertainty in terms of the scale of the economy in relation to the size of the biosphere. This helps illustrate the relevance of uncertainty to sustainability from a somewhat different perspective.

Daly (1992) states that it is assumed in economic theory that the undisturbed, natural state of an environmental resource is represented in economic decisions as a possible use of the resource. He notes that the economic subsystem has grown to the point where its demands on the biosphere are significant, and cannot be disregarded. In neoclassical theory, he argues, this has the implication that the biosphere is, effectively, a sector within the economy, receiving an allocation of resources, based on the willingness to pay of individuals. The allocative decisions applying to each resource are assumed to include that resource's "use" in nature, along with its other possible uses.

Theory predicts that efficient allocation will prevail as environmental services become scarce, provided that the correct positive prices are found. A commodity's price reflects the value of the next best commodity to which the factors embodied in it could have been allocated. In the same way, the extent of development of natural resources is taken to reflect individual

decisions balancing marginal environmental costs against marginal benefits (Daly, 1992).

In practice, however, Daly (1992) argues that nature is excluded from this system where opportunity costs are measured by market prices. As stated above, the reality is that our knowledge of the external costs associated with ecosystem disruption is inadequate. Shadow prices valuing the use in the biosphere of natural resources, in terms comparable to the prices of commodities, are not reliably known. Further, there is no basis for assuming that increasing stress on ecosystems will lead to the loss of their services in order of their increasing usefulness to mankind. Thresholds and interdependencies in the responses of ecosystems to disturbance are poorly understood, and cannot be represented by smoothly increasing marginal cost functions.

Daly (1992) concludes that, largely for reasons of uncertainty, the objective of sustainable scale of the economy is not adequately addressed by the price system. It is a weakness in the economic approach to sustainability that we attempt to subsume scale under allocation. Economics could better address issues of sustainability by dealing with efficiency and scale independently. This is exemplified by systems of marketable emissions permits.

Whether or not Daly's argument, that the scale of the economy is not reflected in the price system, is entirely accepted, it serves to emphasise the significance of the uncertainty surrounding the impacts of economic activity on the natural world. Many environmental costs of economic activity remain mostly external to the price system. To the extent that economic theory addresses such issues by assuming perfect knowledge on the parts

of individuals, and allowing each to decide on his willingness to pay for the loss of environmental services, the economic approach to sustainability is undermined by our lack of knowledge of environmental costs and benefits.

Further, as with irreversibility, global environmental issues are, perhaps, among the situations where uncertainty is most significant. Global warming due to greenhouse gases, and ozone depletion, are examples. In addition to the uncertainty and irreversibility associated with such environmental problems, major political barriers exist to the internalisation of externalities at the international level. Thus the environmental costs inherent in these problems will tend to remain outside the price system for political reasons as well as for reasons of uncertainty.

Several ways have been described above in which the economic approach to sustainability is impeded by uncertainty, or lack of information. First, uncertainty and irreversibility have implications for the extent to which environmental and man-made assets may be substituted. Consequently, extensions of economic optimisation, with its assumptions of substitutability, to include environmental costs and benefits, are partially invalidated. As well, our ability to make appropriate allocative decisions is impaired by ignorance as to their environmental implications. It is not necessarily possible to identify efficient allocations. Finally, where sustainability is distinguished from efficiency, it is largely for reasons of the same ignorance that it is impossible to identify whether a given time path is sustainable.

3.5 SUMMARY

In practice, ignorance is sufficiently extensive as to deny the possibility of identifying whether or not any given economy is on a sustainable time path. Lack of information about the needs of future generations is a problem common to all approaches to sustainability. Based on recent history, economists have tended to take a relatively optimistic view. Modern economies, it is argued, create strong incentives for improvements in technology and institutions. These, in turn, allow increased exploitation of substitution possibilities which can offset losses of natural capital (Bishop & Woodward, 1994).

Ecologists, on the other hand, adopt a strategy which examines the impacts of economic activities on ecological systems. Emphasis is placed on safeguarding ecological stability, and on the long-run constraint imposed by biological evolution (Costanza, Daly & Bartholomew, 1991; Rennings & Wiggering, 1997).

The substitutability of natural capital by other forms of capital, which has often been assumed by economists, is denied in much of the ecological literature. Of special note in this connection, as stated above, are the life-support functions of ecosystems. These functions, dependent on biodiversity and ecosystem integrity, have been particularly difficult for economists to value (Pearce & Atkinson, 1995). Thus, elements which are central to the ecological approach to sustainability present a stumbling block to the economic approach.

Clearly, the ecological and economic approaches to sustainability are very different in their assessments of the substitution possibilities of man-made and natural capital, and of the ability of technology to enhance them. This is particularly true in contexts where the integrity of ecosystems is threatened. Ecologists have tended toward the conclusion that ecosystems must be maintained in their natural form. The substitution assumptions of weak sustainability, accepted by many economists, are largely rejected by ecologists.

Finally, it should be acknowledged that the above discussion has made a somewhat simplistic distinction between the economic and ecological approaches to sustainability. To the extent that the debate between economists and ecologists has been simplified to two positions, some qualification is needed. It should be emphasised that some economists have advocated approaches that recognise the need to maintain ecosystem integrity. For example, Pearce and Atkinson (1995) have suggested that, at present, a strong sustainability rule is the appropriate constraint on behaviour.

CHAPTER 4: POSSIBLE RULES TO ACHIEVE SUSTAINABLE DEVELOPMENT

4.1 THE HARTWICK-SOLOW APPROACH

In 1977, John Hartwick proposed a rule to ensure non-declining consumption over time in an economy utilising non-renewable resources. He showed that non-declining consumption is possible as long as the total capital stock is not depleted over time. The total capital stock could be maintained by reinvesting the Hotelling rents from extraction of non-renewable resources in man-made capital. Thus as the stock of non-renewable resources is depleted, the stock of man-made capital increases to replace it. Hotelling rents are those arising from an inter-temporally efficient extraction program. (Hartwick, 1977). Further, Toman, Pezzey, and Krautkraemer (as cited in Hanley, Shogren, & White, 1996) point out that these resource rents must be measured using prices which reflect a sustainability constraint.

Three major criticisms have been made of the Hartwick rule. First, as noted above, the environment provides utility directly, as well as through inputs to production. Thus, non-declining consumption is distinct from non-declining welfare. Second, the rule depends on the particular functional form chosen for the aggregate production function. The functional forms used by Hartwick do not realistically reflect the supply limitations of natural resources (Hanley, Shogren, & White, 1996). Third, the degree of substitutability between man-made capital and natural capital is probably lower than the Hartwick-Solow approach suggests. It is often argued that natural and man-made capital are generally complements rather than

substitutes. Usually, both types of input must be increased in order to increase output (Christensen, 1989; Daly, 1990).

4.2 NON-DECLINING CAPITAL STOCK APPROACHES

The London school has tried to address the issue of the limited degree of substitutability between natural capital and man-made capital in a different way (Pearce, Barbier, & Markandya, 1990). They have taken the view that there are many elements of natural capital which cannot be substituted in the economy. Such “critical” natural capital includes nutrient cycling processes and the processes that regulate the composition of the atmosphere. These are ecosystem functions which are necessary for man’s survival, and it is important to maintain them. The natural resilience of the ecosystems involved must be protected (Hanley, Shogren & White, 1996).

From this, it follows that there is a part of the natural capital stock which must be preserved if future generations are to achieve the average level of utility held by this generation. Thus, maintaining part of the natural capital stock becomes a rule for sustainable development. Three possible answers to the question of how much of existing natural capital must be maintained are: (1) the existing level, (2) the level that would maintain the critical element of natural stock, and (3) some amount in between.

Here there arises a barrier to operationalising any such rule for sustainable development. There is no way of aggregating the different elements of natural capital in comparable units, in order to quantify their values. It is necessary to express the various types of natural assets in a

common numeraire, in order to aggregate them. The most obvious unit is money; physical units allow no way of adding a forest to an area of grassland. Even if natural assets are simply to be held constant, it will be necessary to define the value of each asset at its existing level. For example, it will matter that a hectare of one type of forest will be less valuable than a hectare of a different type of forest (Hanley, Shogren, & White, 1996). It will also matter within which geographic area stocks are held constant. This is the issue of spatial aggregation (van Pelt, 1993). The approach of maintaining specific categories of natural capital at a constant level has been suggested (van Pelt, 1993). This is a partial answer to the problem of aggregating natural capital stock. Possible categories include biodiversity, pollution assimilation capacity, and the integrity of nutrient cycles.

A sustainability rule suggested by the London school is to prevent reductions in the level of natural capital below some constraint value, or series of constraint values for respective categories of natural capital. If the present level is chosen as the constraint value for any category of natural capital, this could be a very heavy restriction. All projects having negative effects on those categories would be precluded. To provide an alternative to this outcome, Pearce, Barbier and Markandya (1990) have proposed the use of "shadow projects". These are projects that will result in environmental benefits, or additions to natural capital, in amounts to offset the losses of natural capital resulting from a given collection of projects with harmful environmental effects. The biggest single problem with this scheme is, again, that of valuing the various elements of natural capital involved, so that gains and losses can be compared (Hanley, Shogren & White, 1996).

4.3 THE SAFE MINIMUM STANDARDS APPROACH

The safe minimum standards (SMS) approach is closely related to that of non-declining natural capital stock. The SMS approach comes from decision making under uncertainty. This approach recognises that society is unsure about the future consequences of environmental degradation, and attempts to take this uncertainty into account explicitly. In the words of Ciriacy-Wantrup (1985), this is done by "subjecting the economic optimum to the restriction of avoiding immoderate possible losses." Accordingly, the idea of a safe minimum standard of conservation is adopted. If we are unsure about costs of environmental degradation, then deciding to conserve a resource is the risk-minimising course of action, since conservation can minimise the maximum possible loss to society. The SMS rule is as follows:

> ...prevent reductions in the natural capital stock below the safe minimum standard identified for each component of this stock unless the social opportunity costs of doing so are 'unacceptably' large. (Hanley, Shogren, & White, 1996, p. 430)

Two practical problems arise with this approach. First, how are SMS levels to be identified? A safe minimum standard of conservation, in a given resource class, is achieved by avoiding the critical zone, i.e. those conditions brought about by human action where it becomes uneconomical to reverse environmental damage (Ciriacy-Wantrup, 1985). However, in practical terms, how is the critical zone to be recognised? For flora and fauna, these SMS levels have been identified as corresponding to the

minimum viable population levels in a given area. An example would be the smallest population of spotted owls in the Pacific North-West that will ensure the survival of the species in this area (Hanley, Shogren, & White, 1996).

A second practical problem with the SMS approach concerns the identification of “unacceptably large” opportunity costs of preservation. This can be done by social consensus. However, in this case, only the preferences of the current generation are reflected.

The SMS approach differs from the critical natural capital approach, above, in that it allows society to breach the safe minimum standard for a resource if the opportunity costs of preserving the SMS are seen as unacceptably high. The critical natural capital approach requires that critical natural capital stock be protected regardless of cost (Hanley, Shogren, & White, 1996). In the SMS approach, the benefits of preservation are treated as unknown, and do not enter the SMS rule directly. This approach does not require us to quantify unknowable future losses due to current development projects; rather, biodiversity is placed beyond the reach of simple trade-offs. It avoids some of the limitations imposed on the critical natural capital approach by problems of aggregation and valuation.

4.4 DALY'S "OPERATIONAL PRINCIPLES"

Daly (1990) has identified what he calls "operational principles" to bring an economy toward sustainable development. These principles are as follows:

1. For renewable resources, harvest rates should not exceed regeneration rates, keeping in mind that growth rates for such resources are dependent on population density.
2. Rates of waste emission should not exceed the assimilative capacities of the ecosystems in which the wastes are deposited.
3. The exploitation of a non-renewable resource should be paired with an offsetting investment in a renewable resource that can substitute for it. The receipts from extraction of the non-renewable resource are split into two components: an income stream that can be consumed immediately, and a capital component to be invested in the renewable alternative. The distribution of receipts between income and capital components depends on the life expectancy of the non-renewable resource being exploited, and on the rate of growth of the renewable substitute. By the time the non-renewable resource has been economically exhausted, the renewable substitute is to provide consumption equal to the initial income component of the receipts from the non-renewable resource (El Serafy, as cited in Daly, 1990).
4. The overall scale of the economy should remain within the carrying capacity of its physical area, in the sense of maintaining the population without resorting to capital consumption. This implies limitations on resource throughput, which in turn implies a trade-off between population size and per capita resource use (Daly, 1990).

To what extent are Daly's rules operational? The calculation of the investment stream from non-renewable resources would be very difficult in practice. Likewise, it would be very difficult to identify the maximum or optimal scale of resource throughput for an economy. Also, a high level of scientific uncertainty remains in the matter of the assimilative capacities of ecosystems for many pollutants. There are many information gaps to be filled before these rules could be implemented with much accuracy (Hanley, Shogren, & White, 1996).

4.5 VALUATION OF ENVIRONMENTAL SERVICES AT CORRECT SHADOW PRICES

It might be expected that incorporation of non-market values for environmental services into decision making, would lead an economy to move toward a sustainable development path. The incorporation of these values would require that all environmental externalities be correctly valued, and the values reflected in decisions made by individuals, firms and governments. In fact, the use of correct shadow prices is essential to allow an economy to be intertemporally efficient in its use of resources, and can go a long way toward preventing resource overuse. However, as is illustrated below, it would not necessarily lead to sustainability (Hanley, Shogren, & White, 1996).

Applying the usual cost-benefit analysis criterion to a portfolio of development projects requires that the following be satisfied for the discrete time period $t = 1 \ldots T$,

$$\sum_{t=1}^{T} B_t \delta_t - \sum_{t=1}^{T} C_t \delta_t - \sum_{t=1}^{T} E_t \delta_t > 0$$

where natural capital is measured in monetary units, and

B_t is the benefits from the portfolio,

C_t is the non-environmental costs,

E_t is the environmental costs, and

δ_t is the discount factor.

Thus the net benefits (B_t - C_t) of development are required to outweigh the environmental costs (E_t). However, this is entirely consistent with declining environmental quality, and thus with declining natural capital. Certainly where sustainability is taken to require non-declining natural capital, correct valuation of the environment will not necessarily lead to sustainable development, unless shadow project constraints are implemented (Hanley, Shogren, & White, 1996).

This goes some way to illustrate the distinction between efficiency and sustainabiity, and the fact that only a subset of efficient paths is also sustainable. As noted in the previous chapter, even a weak sustainability criterion is not necessarily met by ensuring efficiency. It has been argued that many of today's environmental problems cannot be adequately defined and addressed in terms of efficiency alone (Bishop & Woodward, 1994). To ensure non-decreasing opportunities for the future may require more fundamental changes than are implied by efficiency considerations.

4.6 CONCLUSION

Several of the sustainability rules above reflect a recognition that the scope of environmental economics as it has evolved, toward correction of market failures, is too limited. As Bishop and Woodward (1994) have identified, there is a need for environmental economics to broaden its framework so that sustainability is explicitly addressed, along with efficiency. The sustainability rules above comprise a variety of approaches to this problem. Most of them have in common decision procedures which are somewhat extrinsic to established economic theory, and which attempt to introduce biophysical constraints. This is true of constraints on natural capital stock, of the safe minimum standards approach, and of the restrictions on the scale of the economy contained in Daly's "operational principles". These rules may be said to reflect the effort of economists to achieve what Victor has termed "a more appropriate conceptualization of the interdependency of the economy and the environment" (Victor, 1991, p. 211).

The above rules for sustainable development reflect a variety of attitudes to the substitutability of man-made and natural capital. The Hartwick-Solow approach assumes a high level of substitution to be possible. While this is perhaps the most operational of the rules described above, its treatment of the fixity in supply of natural resources, and of the substitutability of natural and man-made capital, are very open to criticism.

The above rules for sustainable development have in common that, for the various reasons identified above, they are not readily operational. The usefulness of these rules is limited by shortcomings in our knowledge in several areas. First, our scientific knowledge of ecosystems is generally

not sufficient to allow us to judge the amount of pressure from human activities that a given ecosystem is able to withstand before collapse or irreversible change occurs. This is relevant to the harvesting of renewable resources and to the use of the natural environment as a sink for pollutants. Second, we are essentially unable to aggregate natural capital in physical terms, and our ability to value natural capital is limited. Third, and closely related to valuation, future consumer tastes and technological developments are unknown; consequently there is no reliable means of representing future generations in current decisions.

Given the implementation problems with the above rules, we move on to the next best approach of looking for ways of tracking our progress toward sustainable development. This brings us to indicators of sustainable development, which might show whether an economy is becoming more or less sustainable.

CHAPTER 5: SUSTAINABILITY INDICATORS

5.1 INTRODUCTION

The discussion in this chapter turns from the subject of rules to achieve sustainable development, to a more operational level. We turn, then, to the subject of indicators of sustainable development. Indicators are the means by which sustainability is measured, and the progress of an economy toward a sustainable path is monitored.

This requires that we address issues of data quality, and of the processes of data collection, as well as the assumptions, discussed above, that underly the analysis of sustainability. It has been identified as a priority to address the weaknesses of the present empirical base for decisionmaking in the area of environmentally sustainable development (World Bank, 1995).

In this chapter, a brief overview is presented of the issues involved in developing indicators of sustainability. Some of the various types of sustainability indicator currently being implemented are briefly discussed. The issues of scale constraints, the substitutability of natural and man-made capital, and of uncertainty regarding future technology and consumer preferences, were summarised at the conclusion of the previous chapter on sustainability rules. These issues are relevant to all attempts to operationalise sustainability. Measurement issues relevant to sustainability indicators are also described, particularly those of aggregation, substitutability of assets, and discounting. Finally, the specific indicators implemented in this thesis for the province of Alberta, environmentally-

adjusted GDP (EDP) and the Pearce-Atkinson Measure (PAM), are introduced.

5.2 WHAT IS AN INDICATOR?

In measurement theory, the term "indicator" is applied to the empirical specification of concepts not capable of being fully operationalised on the basis of generally accepted rules. An indicator is thus a representation of a component or process of a real world system (Vos et al.'s 1985 study, as cited in van den Bergh, 1996).

The primary function of an indicator is simplification, in the sense that it provides a compromise between scientific accuracy and the need for succinct information (Kuik & Gilbert, 1999). It is a concise expression of information, or a tool to deliver information in a comprehensible, useable form (McRae, Hillary, MacGregor & Smith, 1995). Good indicators are those that combine the properties of adequately representing complex processes, and of effectively supporting decision making (Vos et al.'s 1985 study, as cited in van den Bergh, 1996).

Five key characteristics of indicators have been identified in the literature (McRae, Hillary, MacGregor & Smith, 1995; van den Bergh, 1996):

- Scientific rigour and replicability. The indicator should be uniquely representative of the problem and system under consideration, and must have a scientific basis (ideally based on an empirically tested

model, otherwise based on an expert consensus of available scientific knowledge).

- The indicator must be quantifiable. Data must be available or obtainable with existing technology, at reasonable cost, and should meet current standards of reliability and reproducibility.

- Regional sensitivity. The indicator must be capable of operating effectively across a range of geographically diverse areas.

- The indicator should clearly represent an identified part of a cause-effect chain in the system in question. While the indicator need not reflect all parts of the cause-effect chain, there should be no ambiguity as to which parts it does and does not represent.

- Policy relevance. The indicator should offer implications for policy. Policies can be implemented at various points on the cause-effect chain. The indicator, as a representation of a part of this chain, should either reflect the effectiveness of past policy, or suggest options for future policy.

5.3 INDICATORS OF SUSTAINABILITY

Indicators of sustainability are distinguished by the need to combine information on social, economic and environmental trends. This presents a difficult challenge in terms of simplifying complex phenomena. Our growing understanding of the complexity of sustainability is somewhat in

conflict with the demand for simplified representations, in the form of indicators (International Institute for Sustainable Development, 2000).

In line with the tension between the complexity of sustainability, and the need to summarise its characteristics, and highlight trends, there is a debate as to whether it is possible to adequately describe sustainability with a single indicator. It is often argued that no single indicator can adequately communicate the broad range of information encompassed by sustainability.

Arguments against the development of a single indicator of sustainability tend to focus on the diversity of biological systems. For example, an information gap often identified in the measurement of sustainability is in the area between the disciplines of economics and ecology. We still lack an analytical framework that effectively integrates ecological and socio-economic systems (Lange, 1999). Economic activities ultimately depend on the health of the ecosystems supporting them. A key need that has been identified is for improved indicators to signal increasing scarcities of the resource base, including loss of ecosystem resilience (Arrow et al., 1995). In this connection, it has been argued that any evaluation of sustainability must be based on biophysical assessments. Such assessments, the argument continues, are unlikely to be compatible with any single-numeraire approach to quantifying sustainability (Lange, 1999).

Consider the single-numeraire indicator at the level where it is implemented in policy decisions. The use of any single, all-encompassing indicator in decision making will tend to lead to much of its information being ignored. In the application of such a simplified measure, a danger

exists that awareness will be lost of the assumptions, weightings and uncertainties inherent in it. To this extent, the value of a single indicator of sustainability as a policy tool is open to question. It is likely that a need will remain for multiple indicators, in addition to single, systemic ones, to adequately assess a subject as complex as sustainability (Costanza, 2000a).

On the other hand, to the extent that sustainability can be quantified in a single indicator, this approach has the advantage of providing information in a form that is relatively easy to interpret in decision making. It also makes information relatively accessible to the public. Such indicators have the advantage of simplifying complex information to a single, clear message. If a single-numeraire indicator, such as green GDP increases over time, this is clearly a good thing. The indicator has performed the decision-making function of reducing several criteria to one simple comparison (Costanza, 2000a). Further, in the case of green GDP, it is positioned so as to have some ability to compete with the political power of GDP (International Insititute for Sustainable Development, 2000).

5.3.1 Types of Sustainability Indicator

The varying degrees to which different sustainability indicators condense information was discussed in the previous section. This has been used as a criterion for classification of sustainability indicators, as follows (World Bank, 1997).

- A systemic indicator (also “portfolio” or “synoptic” indicator) is a single indicator that attempts to assess the status of a complex system, e.g. environmentally-adjusted GDP (EDP) for a nation.

- Thematic indicators represent a lesser extent of information reduction. Typically, where this approach is adopted, a small set of indicators is developed for each of several environmental policy areas. Within that structure, thematic indicator sets are often broken down by position on the causality chain, distinguishing indicators of pressure, state and response. This is in accordance with the widely adopted conceptual framework developed by the Organisation for Economic Co-operation and Development.

  Commonly, a thematic indicator reflects pressures from a given sector of the economy on the environment (and impacts of environmental change on the socioeconomic system) (Kuik & Gilbert, 1999). An example is Statistics Canada's Material and Energy Flow Accounts, which document the resource and waste intensity of various economic activities.

- Individual (or "atomistic") indicator sets involve the least data aggregation. The sets are relatively large, sometimes containing over a hundred indicators, and, again, they are often structured according to a pressure-state-response framework. The entire set may be designed to present a balanced view of sustainability, and a few indicators may be selected for a specific purpose.

As discussed in the previous section, this spectrum of information reduction reflects a trade-off between simplification and completeness of information. The usual alternative to single-numeraire or systemic indicators is vectors of atomistic indicators, some reflecting improvement, others showing deterioration. This may constitute a more complete picture,

but it also delivers a more ambiguous message: what does such a set of indicators say about sustainability as a whole? Admittedly, no single indicator tells us all we would like to know, but neither is there a universally accepted weighting system to apply to atomistic indicators (Hanley, 1996).

This highlights a weakness of large sets of atomistic indicators. Clearly, though, if highly aggregated, systemic indicators are to be developed, some issues have to be addressed concerning the ways in which information is aggregated.

5.3.2 Measurement Issues to be Addressed by Sustainability Indicators

Information relevant to environmentally sustainable development often has elements specific to a certain physical location. The development of indicators of sustainability from such location-specific information raises some issues. Does a given physical attribute have the same significance in one ecosystem as in an adjacent ecosystem? In what ways does aggregation of such information alter or bury its significance? Furthermore, as decisions are implemented as to how such data should be compiled in order to best reflect environmental sustainability, to what extent is technical rigour compromised? These issues surrounding the aggregation of specific information into indicators need to be addressed: consensus must be developed on appropriate protocols for synthesising specifics into more aggregated measures (World Bank, 1995).

A closely related issue to those of aggregation and site-specificity concerns the weighting schemes inherent in composite indicators, or indices. These are often open to debate. In certain cases, the elements of

an index may be weighted according to scientific knowledge: for example, emissions of various greenhouse gases could take the respective climatic impacts of the gases as a weighting factor (Hardi & Barg, 1997). In many instances, however, no such obvious basis exists for the weighting of the elements in an index. Differences of quality in the factors being combined tend to become hidden. Consensus still needs to be established in the matter of procedures, such as sensitivity analysis, for testing and characterising alternative weighting schemes. The weighting rule adopted has an influence on the way in which the underlying information is reflected in the composite indicator (World Bank, 1995).

One possible mechanism for weighting the components of a composite indicator is the use of the relative monetary values of goods and services produced, as in the case of GDP (Hardi & Barg, 1997). This has the advantage of applying a common metric to diverse elements. Indicators in monetary units have the additional advantage of consistency with existing macroeconomic indicators. Environmentally-adjusted GDP (EDP), for example, makes information about sustainability relatively accessible to policy makers (van den Bergh, 1996).

Kuik and Gilbert (1999) identify a second approach to the problem of integrating multidimensional information. This involves the use of multicriteria techniques to evaluate information with different dimensions. The weakness of this approach is that these techniques depend on a degree of subjective weighting of the elements of sustainability.

The issues of aggregation and weighting must be addressed in any attempt to quantify sustainability. Where systemic indicators are used, these issues must be addressed within the structure of the indicators, rather

than in subsequent decision-making processes. Similarly, dynamics such as relative scarcity changes of assets over time need to be reflected in measures of sustainability. Whether implicitly, or explicitly, as in the application of discounting, some stance with respect to the future inheres in any sustainability indicator (van den Bergh & Verbruggen, 1999; van Kooten & Bulte, 2000). As well, systemic sustainability indicators must reflect the degree to which natural and man-made assets may be substituted. The disciplines of ecology and economics are markedly different with respect to these features of sustainabiliity indicators.

5.3.3 Ecological and Economic Indicators of Sustainability

Ecologists' indicators of sustainability have tended to be measures of strong sustainability, measured in physical units. Examples of ecologists' sustainability indicators include measures of carrying capacity and of system resilience. Taking the former example, an ecosystem's carrying capacity defines an ecologically-based sustainability constraint. Implicit in this is the argument that sustainability is diminished unless all the identified ecological constraints are observed. Substitutability between assets is effectively denied (Pearce, Atkinson, & Hamilton, 1998). Further, the costs of not exceeding the carrying capacity of any ecosystem are not a part of this indicator. If these costs happen to be substantial, then sustainability, defined as non-decreasing welfare over time, may be diminished even though carrying capacity is not exceeded.

The economic approach to sustainability has generally led to indicators of weak sustainability, in monetary units. Unlimited substitution between man-made and natural capital is assumed. A key limitation of indicators constructed in monetary units relates to valuation, particularly in

the area of environmental degradation. Our ability to value these aspects of environmental assets remains limited. Consequently, such indicators either fail to reflect all elements of sustainability, or they rely to some extent on strong and controversial assumptions (Kuik & Gilbert, 1999). Thus, while market prices provide a powerful mechanism for summarising information, a trade-off is involved.

As noted above, Arrow et al. (1995) have identified the need for indicators to signal impacts of economic activity on the environment. In the words of van den Bergh and Verbruggen (1999), sustainability indicators should point to the right trade-offs between economic, social and biophysical objectives. These two statements identify the policy objectives relevant to sustainability indicators. They also highlight the measurement issues identified above, particularly with regards to integrating information from different disciplines.

In economic appraisal, changes in human well-being can be linked to environmental degradation and resource depletion, and connections between environmental and economic elements can be analysed (Pearce, Atkinson, & Hamilton, 1998). This argues for the ability of economic theory to encompass sustainability. Within the limits of valuation, noted above, economics provides a mechanism for handling the trade-offs between efficiency, equity and environmental sustainability. Further, it is arguable that economic approaches are relatively well developed in terms of the measurement issues central to sustainability indicators. The issues of aggregation, discounting, substitutability, and valuation, although not entirely resolved in economics, have benefited from many decades of work in constructing money metrics for policy analysis. How these issues are addressed is important: different ways of aggregating data, or different

assumptions about the substitutability of natural and produced assets, can lead to different conclusions about sustainability (van Kooten & Bulte, 2000).

5.3.4 Environmentally-Adjusted GDP (EDP) and the Pearce-Atkinson Measure (PAM)

This thesis deals with the implementation of two sustainability indicators, environmentally-adjusted GDP (EDP) and the Pearce-Atkinson measure (PAM). Both are systemic indicators, based on economic theory. These indicators define sustainability in terms of non-declining human wellbeing, and they define the conditions for achievement of sustained wellbeing in terms of capital stocks (Pearce, Atkinson, & Hamilton, 1998).

EDP is a measure of national income, modified to reflect depletion and degradation of the environment. It identifies the highest level of consumption that can be sustained, i.e. sustainable income. Declining EDP over time indicates non-sustainability. The Pearce-Atkinson measure is a measure of net saving (gross savings net of depreciation of produced assets) adjusted to include environmental depletion and degradation. Persistent negative values for PAM would reflect declining capital stocks, and must lead to non-sustainability. By directly addressing changes in capital stocks, the Pearce-Atkinson measure is perhaps richer in terms of policy implications.

Both these indicators utilise a monetary metric, in an economic framework. The aggregating power of market prices is thus utilised, and applied to some extent to environmental as well as economic elements of sustainability. Arbitrary weighting schemes are avoided. The frameworks

provide mechanisms to handle trade-offs between economic and biophysical elements, to the extent biophysical elements can be valued, and to the extent the frameworks apply valid assumptions concerning the substitutability of man-made and environmental assets. Unlimited substitutability is assumed between natural and produced capital. This allows inclusion of costs of environmental conservation, for example.

Both indicators, although they do not incorporate technological change, tend to lead to relatively optimistic judgments, by virtue of their assumptions concerning (unlimited) substitutability of assets. The question of how much substitutability should be allowed is hard to resolve. Empirically, little is known about what should be classified as critical natural capital (for which substitutes are essentially absent). A key question for future research concerns the extent to which substitution of produced for natural assets remains as effective as it has been in the past (Pearce, Atkinson, & Hamilton, 1998).

The scope for further investment in technology and human capital is often cited as cause for optimism, while ecological dimensions give rise to pessimism. These empirical facts reflect a type of distinction which is not well represented in our indicators. In this sense, the unlimited substitution in our frameworks between produced and natural assets does not handle trade-offs entirely adequately. Ultimately, it is likely that sustainability requires both that total capital be maintained, and that stocks of critical natural capital be maintained (Pearce, Atkinson, & Hamilton, 1998).

CHAPTER 6: RATIONALE BEHIND EDP AND PAM

6.1 INTRODUCTION

In this thesis, two macroeconomic indicators of sustainability are implemented for the province of Alberta. The first, environmentally-adjusted GDP (EDP), involves adjustment of the conventional provincial income accounts for natural resource depletion (i.e. EDP_1, defined below). This gives an estimate of sustainable income. The second indicator implemented is the Pearce-Atkinson measure (PAM), a test of weak sustainability. This chapter outlines the rationale behind these two indicators, and describes their construction.

6.2 ENVIRONMENTALLY-ADJUSTED GDP (EDP) - OVERVIEW

It is widely understood that conventional national income accounts do not give an accurate picture of the value of a nation's economic activity. A common measure of national income is gross domestic product (GDP). As a measure of the contribution of a country's economy to the welfare of its people, however, GDP is, at best, incomplete. If two countries produce the same GDP, but the first wears out significantly more of its capital stock in doing so, then it is clear that the second country is serving its citizens better. This much is recognised in conventional national accounts with regards to man-made capital: depreciation of man-made capital is routinely deducted from GDP to give net domestic product (NDP) (Solow, 1992).

However, the same principle is not routinely applied to natural resources and environmental assets. In an example analogous to the one in the previous paragraph, consider two economies producing the same NDP, but the first doing so by depleting natural resources and degrading its natural environment. Again, the second economy is contributing more to the welfare of its citizens. However, the distinction is not recognised in published national accounts, because no adjustments are made for changes in natural resource stocks and environmental assets. The need for measures of sustainable economic activity dictates that flows of natural capital, as well as man-made capital, be accounted for (Solow, 1992).

6.2.1 EDP_1 and EDP_2

To address this need, World Bank researchers have defined two extensions of NDP to account for natural capital. EDP_1 is defined as NDP adjusted for depletion of natural resources, for example oil and minerals extracted and timber harvested. EDP_2 incorporates further adjustments for the value of environmental degradation. Thus EDP_2 is EDP_1 less estimates of the value of such elements as water and air pollution, soil erosion and lost wildlife habitat (Steer & Lutz, 1994).

6.3 PEARCE-ATKINSON MEASURE (PAM) - OVERVIEW

The Pearce-Atkinson measure provides a simple, intuitive test of the sustainability of an economy. It is a test of weak sustainability, which means that it accepts the assumption that man-made capital and natural capital may be substituted. An economy is found to be sustainable if its savings (and, implicitly, investments) are at least as great as the sum of

depreciation of man-made and natural capital. Owing to the weak sustainability assumption, this test reflects a basic, zero-order condition for sustainability (Pearce & Atkinson, 1993). If a country fails this test of weak sustainability, it is unlikely to pass a more rigorous test.

6.4 BACKGROUND TO HARTWICK'S RULE

As outlined in the second chapter of this thesis, current economic definitions of sustainable development tend to focus on non-declining well-being over time (Pearce, Barbier, & Markandya, 1990). As described by Pearce and Atkinson (1995), several authors have identified a relationship between non-declining utility, or well-being, and the underlying capital stock. A well-established line of analysis has thus identified non-declining capital stock as a key condition for sustainable development.

Hartwick (1977) has shown that this relationship between non-declining well-being and non-declining total capital stock equates to a requirement to invest the Hotelling rents from the extraction of nonrenewable resources. The specific context of his analysis is presented in the following paragraphs.

Hartwick (1977) investigated the question of how much of a nonrenewable resource should be extracted by a steady-state economy, and how much output should be invested in new man-made capital (Hartwick & Olewiler, 1998). It was established that consumption can be maintained at a constant level if two rules are followed:

- The stocks of the nonrenewable resource are drawn down at such a rate that Hotelling's r percent rule is always satisfied;

- An amount of current output equal to the Hotelling rent on the extracted resource is reinvested.

An obvious question arises from this conclusion: isn't there a point where the decreasing stocks of the nonrenewable resource force the economy into decreased output and consumption? The relevant assumptions in Hartwick's model relate to, a) the extent to which natural capital (the nonrenewable resource) and man-made capital may be substituted in production; and b) the relative productivities of these inputs. These elements of the model are defined by its use of a Cobb-Douglas production function, with the following restrictions (Hartwick & Olewiler, 1998):

$$Q = K^{\alpha}R^{\beta}L^{1-\alpha-\beta}$$

where Q is output, K is reproducible capital, R is the nonrenewable resource, and L is labour, and

$$\alpha>\beta$$
$$0<\beta<1.$$

The model requires the unitary elasticities of substitution between inputs that are implicit in the Cobb-Douglas production function. The condition $\alpha>\beta$ implies that the share of output ascribable to man-made capital is greater than that ascribable to the nonrenewable resource (Hartwick, 1977). In other words, a technology is assumed which guarantees a minimum level of substitutability between inputs, and in which, roughly speaking, man-made capital is more productive than natural capital (Hartwick & Olewiler, 1998).

The main outcome of this work, the requirement that the Hotelling rents from natural resource extraction be reinvested, so that net investment is zero, has come to be known as Hartwick's rule. This result is fundamental to many economic definitions of sustainability. As described in Chapter 2 of this thesis, the concept of maintaining total capital stock is a theme common to many operational definitions of sustainability. Hartwick's rule, then, is central to much empirical analysis of sustainability, including the two sustainability measures implemented in this thesis, EDP and PAM.

6.5 ENVIRONMENTALLY-ADJUSTED GDP (EDP) - CONSTRUCTION

What Hanley, Shogren, and White (1996) have called the Solow-Hartwick approach to sustainability leads to our first sustainability indicator, environmentally-adjusted GDP (EDP). In this approach, Hartwick's rule is taken as the basis for measuring sustainability. The impact of economic activity on environmental resources is quantified as depreciation of natural capital. In line with Hartwick's rule, the premise behind this indicator is that the Hotelling rents from an optimal programme of resource use must be reinvested in natural or man-made capital (Moffatt, Hanley, & Gill, 1994).

Environmentally-adjusted income, EDP, is aggregate income adjusted for depreciation. Thus depreciation of man-made capital (d_M) and natural capital (d_N) are deducted from GDP:

$$EDP = GDP - d_M - d_N.$$

EDP is our measure of sustainable income: it identifies the highest level of consumption that can be sustained, taking into account depreciation of both

natural and man-made capital. GDP includes consumption and investment. If investment in the economy is less than total depreciation, d_M+d_N, then consumption must be greater than EDP. In this case, consumption is high enough that the capital stock is being eroded. Over time, EDP must fall. Only if the capital stock is increasing can EDP rise over time. Thus if EDP increases over time, it signals sustainability, while decreasing EDP signals nonsustainability.

6.6 PEARCE-ATKINSON MEASURE (PAM) - CONSTRUCTION

The Pearce-Atkinson measure may be thought of as an empirical test of Hartwick's rule. It is based on the premise that an economy is unsustainable unless savings (S) exceed the combined depreciation of man-made and natural capital (d_M+d_N). Savings minus depreciation of man-made and natural capital, then, gives the sustainability indicator PAM. This is conveniently expressed in terms of deviation from marginal sustainability (PAM = 0) if divided through by income, Y:

$$PAM = S/Y - d_M/Y - d_N/Y$$

Where PAM < 0, the economy is falling short of a sustainable path, based on a weak sustainability criterion. The greater a negative value we obtain, the more effort is required to achieve sustainability (Pearce & Atkinson, 1993).

The starting point for the calculation of PAM, then, is gross saving (S). This is the conventional measure of a nation's rate of accumulation of capital. Gross saving is calculated as the residual of GNP minus public and private consumption. It represents the total produced output set aside for the future. This measure of aggregate saving is adjusted for depreciation of

produced assets (d_M), giving net saving. Finally, adjustment is made for the value of changes to the natural resource base, accounting for depreciation (or appreciation) of natural capital (d_N). This gives PAM (World Bank, 1997).

Empirical estimates of PAM may be taken as rapid assessments of whether a combination of resource depletion and deficient saving may be a significant policy concern. The goal of PAM is to make explicit the level of output that is not consumed, and is therefore available to provide welfare for the future. It may be viewed as a one-sided measure of sustainability: positive PAM may or may not indicate sustainability, but consistently negative PAM reflects unsustainable behaviour (Atkinson et al., 1997).

CHAPTER 7: DATA SOURCES

7.1 INTRODUCTION

This chapter describes the data used in this thesis, particularly those data quantifying the depreciation of natural capital. A summary of the methodology used by Statistics Canada in the development of these data is presented.

A number of factors have influenced the design of the methodology used to generate the data for depreciation of natural capital. Several theoretical bases for valuation of natural resources were considered. The empirical performance of each of these was examined in the contexts of various Canadian resource industries and markets. As well, particularly in the case of forest resources, data availability has driven the selection of methodology for resource valuation.

7.2 SAVINGS RATE

In the absence of a published savings rate for Alberta, the savings rate used is based on gross savings for Canada. These data were taken from the National Income and Expenditure Accounts (Statistics Canada, 1970...1999). A savings rate for Alberta was derived by multiplying Alberta's GDP by the ratio of Canada's gross savings to Canada's GDP.

7.3 PROVINCIAL ECONOMIC STATISTICS AND DEPRECIATION OF MAN-MADE CAPITAL

Provincial economic statistics were taken from the Alberta Economic Accounts (Alberta Treasury, 1990...1999). Depreciation of man-made capital for the energy and forestry sectors, and for Alberta, is quantified as capital consumption allowance, also in the Alberta Economic Accounts.

7.4 DEPRECIATION OF NATURAL CAPITAL

The depreciation of natural capital is quantified in this thesis using data developed by the Environmental Statistics sub-division of the National Accounts and Environment Division of Statistics Canada. These data are published in Econnections: Linking the Environment and the Economy (Statistics Canada, 2000). Natural capital accounted for in this thesis includes energy resources (crude oil, bitumen and natural gas) and timber.

Valuation of natural capital was done by Statistics Canada, using both the present value method and the net price method, both described below. The choice between these two methods has been made, in part, on the basis of the renewability of each resource. The net price method was used, albeit in combination with the present value method, in the valuation of non-renewable resources. In this context, where the resource is expected to become more scarce over time, the Hotelling model, which underlies the net price method, may be expected to have some validity. On the other hand, the present value method alone was adopted in the valuation of forest resources, the Hotelling model not being applicable to renewable resources (Statistics Canada, 1997).

Both energy and timber assets are characterised by the absence of enough market transactions in asset stocks to allow direct observation of market values. Consequently, in both cases, Statistics Canada's Environmental Statistics sub-division (Statistics Canada, 1997) has made indirect valuations, by estimation of resource rent. Resource rent, in turn, was imputed, rather than observed directly, since, in Canada, not all rent is collected in the form of royalties. Some is collected in corporate income taxes. As well, in the case of timber, stumpage is set administratively, via management agreements, rather than by auction, and may not accurately reflect market value (Statistics Canada, 1997).

7.4.1 Overview of Method of Estimation of Resource Rent

For both timber and energy resources, resource rent was calculated by Statistics Canada as revenue from sales of the resource, minus extraction costs (as described below, a modified procedure has been adopted for energy rent). Extraction costs include operating costs (materials and labour) and costs of produced capital. In the case of the forest sector, government expenditures on forest management were also subtracted from sales revenue (Statistics Canada, 1997).

Except for the cost of produced capital, data for the calculation of resource rent, as outlined above, are generally available in Statistics Canada surveys. Theoretically, the cost of produced capital used in extraction should be estimated as the sum of depreciation and the return to produced capital (see Appendix 1, Part A). Return to produced capital has been interpreted by Statistics Canada (1997) as covering the cost of financing the acquisition of the produced capital stock.

There is significant uncertainty associated with estimating the return to produced capital. Empirically, in situations where resource rent is low, rent sometimes becomes negative following deduction of the return to produced capital. Statistics Canada (1997) have concluded that the method outlined in Appendix 1, Part A for estimation of the cost of produced capital may contain inappropriate assumptions concerning the return to produced capital. Quantification of return to produced capital as $r_i K$ apparently leads to high estimates in subsoil resource extraction industries.

To address the uncertainty inherent in estimating the return to produced capital, Statistics Canada (1997) have derived two estimates of resource rent. The first is a lower-bound estimate that includes return to produced capital. The second is an upper-bound estimate that takes depreciation, alone, to quantify the cost of produced capital (see Appendix 1, Part B). The rent properly attributable to a resource is expected to lie between the two.

For timber rent, this thesis uses a mean of the upper- and lower-bound estimates made by Statistics Canada. Part of the return to capital is thus assigned, somewhat arbitrarily, to the timber resource. For energy, where overestimation of the return to produced capital seems to be more of an issue, the values used in this thesis for resource extraction are based on Statistics Canada's upper bound estimate of resource rent. This is the rent calculation preferred by Statistics Canada (1997) for energy resources, and it is the basis for the stock values estimated for the Canadian National Balance Sheet Accounts.

[illegible]

7.4.2 Energy Resources

7.4.2.1 Outline of Method

Statistics Canada (2000) researchers have developed both physical and monetary accounts for energy resources. These contain estimates of "established" reserves: those reserves that can be recovered under current economic conditions, using current technology.

The rent values used in this thesis for energy resources utilise both monetary and physical accounts. First, a per-unit asset value was derived using the value of the entire asset stock, for each year, from the monetary accounts, and that year's stock size, from the physical accounts. Second, this per-unit asset value was applied to the quantity extracted, from the physical accounts. The (monetary) stock values used in these calculations were derived using the procedure outlined below, in which both the net price method and the present value method are used (Statistics Canada, 1997).

7.4.2.2 Stock Value: Present Value Method

Theoretically, the proper method of estimating the market value of the stock of a natural resource is as the discounted value of the anticipated stream of resource rent. Discounting is appropriate because extraction occurs over a long time, and income earned in the more distant future is worth less from today's perspective (Statistics Canada, 1997).

7.4.2.3 Stock Value: Net Price Method

Uncertainty inheres in the present value method, owing to the necessary assumptions regarding the resource's future prices and extraction costs, and regarding future rates of return. The net price method provides a means of invoking economic theory to deal with this uncertainty: Hotelling's theoretical finding that, in equilibrium, the resource's net price should rise at the rate of return on alternative investments, is used (Landefeld & Hines, 1985).

The net price method, then, assumes the special case where the discount rate exactly offsets the rise of the net price of the resource. The assumptions of the Hotelling model are accepted, and the need for discounting is eliminated. Given these assumptions, the stock of a non-renewable resource may be valued by the net price method: the resource stock is valued as the net price (rent) per unit of the resource, multiplied by the physical size of the stock (Statistics Canada, 1997).

7.4.2.4 Stock Value: Empirical Considerations

The net price method, then, provides a means of addressing the inevitable uncertainties of the present value method of stock valuation. However, some of the necessary assumptions of the Hotelling model, for example that of perfect foresight, are not appropriate in natural resource markets (Landefeld & Hines, 1985). Empirically, the net price method, and the underlying Hotelling model assumptions, fail to describe subsoil asset markets accurately. They tend to overestimate asset value. In Canada, they do not adequately reflect natural and economic constraints in extraction. Specifically, the recent price paths of crude oil and natural gas

in Canada are not as predicted by the Hotelling model (Statistics Canada, 1997).

So far, no international consensus has emerged as to which method of subsoil asset valuation is more appropriate, present value or net price (Hartwick & Hageman, 1993; Statistics Canada, 1997). Empirically, while the net price method, as noted above, tends to overvalue, the present value method tends to underestimate the value of subsoil assets. Consequently, Statistics Canada (1997) have used elements of both the present value method and the net price method to value the stocks of energy assets.

7.4.2.5 Stock Value Calculation

First, for each year, a net price calculation of the value of the resource stock was made, based on the upper-bound estimate of resource rent (i.e. assigning a value of zero to the return to produced capital). This stock value calculation incorporates modifications to reflect the assumptions that, a), the same quantity is extracted each year, and, b), the produced capital used has the same life span as the reserve (see Appendix 1, Part C). These modifications increase the smoothness of the time series. As well, a four-year moving average of this stock value was taken, in order to reduce the impact of price volatility in the present value calcuation, below (Statistics Canada, 1997).

Second, for each year, this stock value was converted to a constant annual stream of revenue over the life of the resource, and a present value calculation was performed (see Appendix 1, Part C). Thus, the discounted value of the total resource stock was obtained. As well as the assumption of constant annual extraction, at current levels, it was assumed that current

resource prices and extraction costs, in real terms, would remain constant over the life of the reserve. The discount rate was chosen to reflect pure time preference, with no risk factor, from a social standpoint. The rate adopted was a real rate of 4% (Statistics Canada, 1997).

7.4.2.6 Rent Calculation

The resource rent values for energy assets used in this thesis are derived from the stock value obtained by Statistics Canada's present value calculation. Each year's stock value was divided by the physical size of the reserve, giving its per-unit value: this was then multiplied by the physical quantity that was extracted in that year, giving a value for the year's rent (Statistics Canada, 1997).

7.4.3 Forest Resources

7.4.3.1 Physical Timber Account

Statistics Canada (2000) have developed a physical account of forest resources. This comprises estimates, in units of timber volume, of the timber stock, and changes in timber stock, on accessible, timber-productive, nonreserved forest land. Thus the physical account only includes forest areas where timber is available for harvesting, and where currently valuable species grow reasonably quickly to merchantable size. This amounts to 35% of Canada's forested land.

The physical timber asset account (PTAA) developed by Statistics Canada (2000) is derived from Canada's Forest Inventory 1991 (CanFI91). This inventory is based on forest resource inventories conducted by

provincial and territorial governments. These generally do not provide consistent data from year to year: they often reflect different land bases from one period to the next. To address these inconsistencies, the PTAA was developed from CanFI91 using a simulation model. In this way, the known impacts of processes of growth, harvesting and natural loss, for the period from 1961 to 1990, were integrated with inventory data for a single year, 1991.

The data taken from CanFI91 describe forest land area, and merchantable volumes of coniferous and broadleaved timber, in 1991. Three forest types are distinguished (softwood, mixedwood and hardwood), and, for most provinces, nine 20-year age classes. In turn, the simulation model evolves an age-distributed forest stock over time, distinguishing three forest types and 180 one-year age classes (Statistics Canada, 1997).

Initially, an age class distribution for the year 1961 was generated, by running a version of the simulation model backward from 1991, integrating inventory data with data on fire, mortality, harvesting, ageing and natural and artificial regeneration. The model was then run forward from this estimated initial condition (Statistics Canada, 1997).

Simulations of forest fires were based on data describing the area burned, by province, for each year. These data were not available on a basis specific to age class or forest type. Consequently, assumptions had to be made concerning the distribution of the area burned in terms of age class and forest type. Similar assumptions were made as to the forest type from which the known volumes of coniferous and broadleaved timber were harvested. These exemplify data deficiencies incorporated in the simulation. Other deficiencies originated in the CanFI91inventory itself,

and some discrepancies arose between the simulated age-class distribution for 1991 and the original inventory (Statistics Canada, 1997).

The simulated distribution for 1991, which constitutes the PTAA, might be viewed as an update of CanFI91, since it reconciles known historical disturbances with the 1991 inventory. Statistics Canada (1997) acknowledge that an improved inventory method is needed.

The PTAA presents annual figures, at provincial and national levels, for total timber stock (in volume units), and changes in stock due to harvest, fire, mortality, road construction and regeneration. These data are the basis for Figures 1 and 2 in Chapter 8 of this thesis.

7.4.3.2 Monetary Timber Account

In addition to the PTAA, Statistics Canada (2000) researchers have developed a monetary timber asset account (MTAA). The two are independent. Rather than utilising any data from the physical account, the monetary account is based entirely on historical production data for timber and other forest products. The MTAA presents annual estimates of the value of the stock of standing timber, for each province and for Canada. These were developed directly from resource rent values calculated for actual shipments of forest products. These rent values are the ones used to adjust Alberta's forest sector income in this thesis. Forest values other than those for marketable timber supply are not yet included in the MTAA.

Annual timber rent, as found in the MTAA, was estimated by subtracting all operating costs and capital costs incurred in felling, transporting and processing of timber from the revenue earned from the

sale of the forest products produced. Data on revenue from forest products are from Statistics Canada sources on value of shipments and inventory changes. Operating costs for the forest industry are also quantified in Statistics Canada sources. Statistics Canada's Investment and Capital Stock Division have prepared end-of-year capital stock values, and have calculated depreciation for the industry. Government expenditures on forest management were also subtracted from revenue: these data are published in the Compendium of Canadian Forestry Statistics (Statistics Canada, 1997).

The industry group considered in the rent calculation comprises both the logging industry and the associated secondary industries selling wood products into public markets. These secondary wood processing industries include the pulp and paper industry, the veneer and plywood industry, and the sawmilling and planing industry. This was done because logging establishments are typically part of integrated firms, and thus do not necessarily "sell" timber at market prices. If, for example, such a logging company reports a low price for sales to its parent mill, then part of the timber rent is effectively shifted to the mill. In this case, rent calculated for the logging industry, in isolation, would be underestimated (Statistics Canada, 1997).

7.5 DISCUSSION

The rent values used in this thesis for the energy sector were derived using a different methodology from that applied to the forestry sector. The estimation of timber rent values followed a simple procedure, subtracting extraction costs from revenues for forest products sold. The values used for

the energy sector are somewhat removed from a straightforward calculation of revenue net of extraction costs. The starting point for each energy resource was a simple rent calculation, consistent with that used for forestry: this was taken through calculations of stock value, with some simplifying assumptions, and the stock value was used as the basis for valuation of the energy resource extracted. This value derived by Statistics Canada for energy resources extracted, was used as rent in this thesis.

This differential methodology is probably a reflection of limitations of the data available for the forest resource. The documentation provided by Statistics Canada (1997) states as a future goal the valuation of harvested timber, in such a way as to account for the impact of harvesting, and other processes, on the age structure of the forest. Such impacts on the forest's age structure may significantly affect the volume available for harvest at future dates. It is noted that this valuation will require very detailed data that are not presently available.

The valuations of extracted energy resources outlined above are perhaps more analogous to the proposed valuation of harvested timber than to simple timber rent. Statistics Canada are, at present, more focused on valuation of resource stocks than on income adjustments, as made in this thesis. This emphasis is reflected in their approach to the valuation of extracted energy resources.

CHAPTER 8: RESULTS

8.1 INTRODUCTION

The two sustainability indicators, environmentally-adjusted GDP (EDP) and the Pearce-Atkinson measure (PAM), are implemented in this thesis. The empirical results are presented in this chapter. Alberta's forest industry is the main focus. To provide perspective on forestry within the entire provincial economy, Alberta's energy industry is also considered.

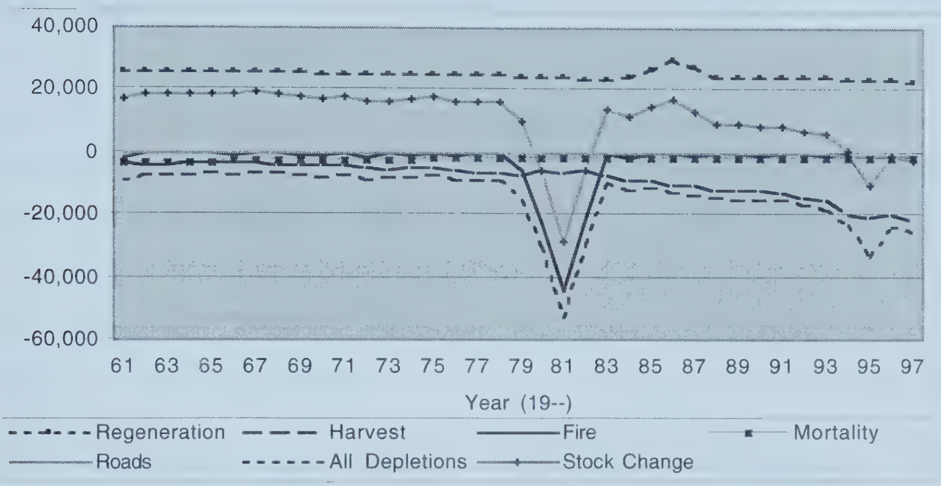
First, the physical changes to Alberta's timber stock, over the past four decades, are described. Next, the changes to Alberta's timber and energy stocks are considered in value terms. The depletion of natural resources constitutes the liquidation of an asset, but is not treated as such in the conventional provincial accounts. The corresponding adjustments are made to the income of Alberta's forestry and energy sectors, and to that of the entire provincial economy. Estimates of EDP, then, are presented for forestry, energy, and the whole of Alberta. Finally, the impact of the liquidation of these same natural resource assets on Alberta's investment profile is considered. In the implementation of PAM, a measure is made of savings which reflects the changes to the natural resource base.

8.2 ALBERTA FOREST INDUSTRIES: PHYSICAL TIMBER STOCK

One approach to the analysis of the sustainability of Alberta's forests involves measurement of physical changes to the timber stock. Figure 1

shows additions to and depletions of Alberta's timber stock, in terms of timber volume, from 1961 to 1997. This includes depletions due to harvest, fire loss, mortality (including disease and insect damage) and road construction. Additions are the result of natural and artificial (planting) regeneration of the forest.

Fig.1. Alberta: Changes in Timber Stock (Volume) [m^3 x 1000]



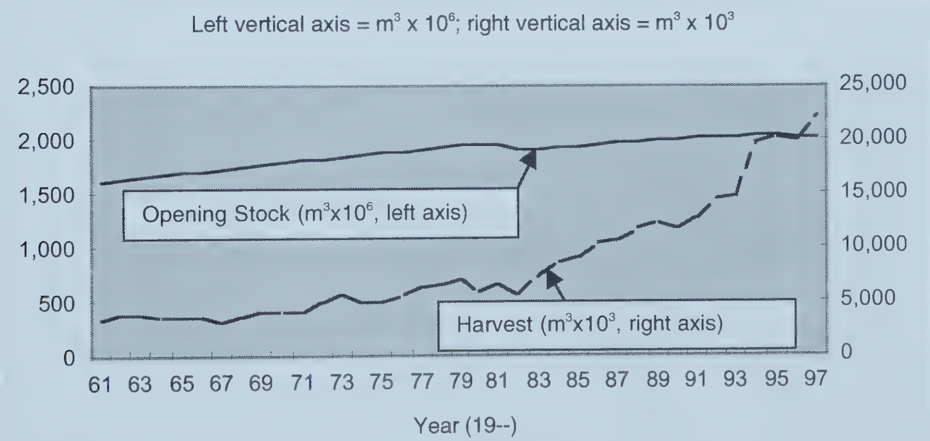
Depletion of the timber stock was mostly due to harvest, except during years of extreme fire loss, namely 1980 to 1982 and 1995. The volume of timber harvested has increased steadily throughout the period shown, particularly in the mid 1980s, and again in the mid 1990s. Forestry policies announced by the Alberta government in 1986 encouraged major investment in the pulp and paper industry. Most notably, Alberta-Pacific Forest Industries (at Athabasca) and Daishowa Canada (at Peace River) brought pulp mills on stream in the early 1990s (Pratt and Urquhart, 1994).

In spite of these increases in the volume of timber harvested, regeneration of the forest has more than outweighed all depletions until

1994. Consequently, Alberta's physical timber stock was increasing until about the time of the advent of these two major mills. Net timber depletion remains quite low: in 1997, about 0.1% of the total stock on accessible, timber-productive, nonreserved forest land.

During the period from 1961 to 1990, Canada's timber stocks declined by about 9%, in volume terms. This reflects the evolution of the use of timber land: it is in transition from virgin forest, composed mainly of mature trees, toward a timber-producing forest, containing a higher proportion of younger, smaller trees (Statistics Canada, 1997). Figure 2 shows the initial stages of the same trend in Alberta, whose aspen stands have only become commercially viable relatively recently. With the increasing volume being harvested, Alberta's total timber volume is not decreasing, as is Canada's, but its rate of increase has already fallen to zero.

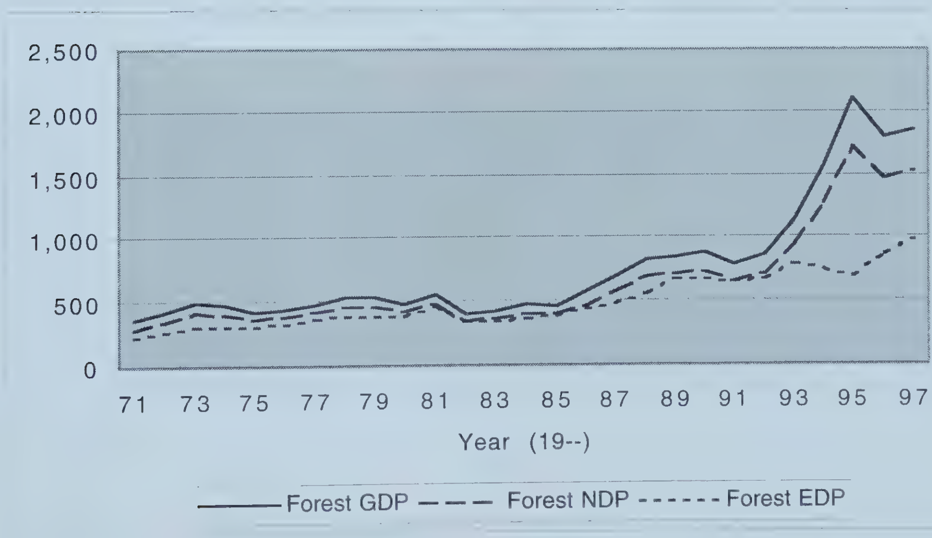
Fig.2. Alberta: Timber Stocks and Harvested Volume



8.3 ALBERTA FOREST INDUSTRIES: EDP

This discussion now turns to analysis of the sustainability of Alberta's forests by adjusting the income of the forest sector for the value of changes to the timber stock. Figure 3 shows gross domestic product (GDP), net domestic Product (NDP) and EDP for Alberta's forest industries. NDP measures the sector's income (GDP), adjusted for depreciation of man-made capital: provincial depreciation rates were applied to the forest industry's share of the provincial economy. EDP measures the forest sector's income, adjusted for both depreciation of man-made capital and depletion of natural capital. Here, depletion of natural capital is quantified as timber harvested, valued at timber rent. Other depletions of the timber stock, due to fire, disease, pests and road construction, are not included. Environmental degradation, from harvesting or other causes, is also not accounted for.

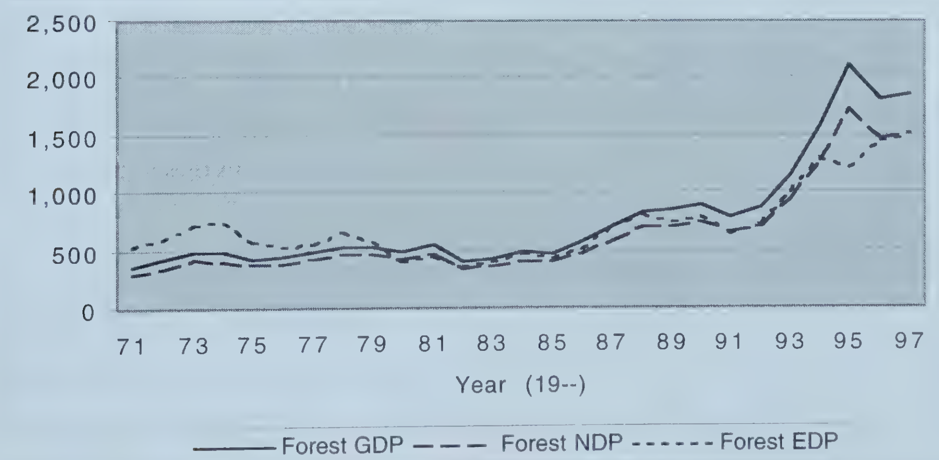
Fig.3. Alberta Forest Industries: GDP, NDP, EDP (Depletions)
[$Millions, 1992]



The forest products industries are subject to a strong business cycle. Consequently, significant fluctuations in annual timber rent result from changing prices and production volumes. In Figure 3, this is most evident around 1995, at which time both the sector's income and timber rent increased sharply. Canada's forest industry enjoyed strong earnings in 1994 and 1995, largely on the strength of high earnings from lumber in 1994, and from pulp and paper in 1995 (Pricewaterhouse Coopers, 1999).

Figure 4 shows GDP, NDP and EDP for Alberta's forest industries, with EDP based on all physical changes to the timber stock, as opposed to harvest only, as in Figure 3. These physical stock changes are the ones presented in Statistics Canada's (2000) physical timber asset account, and summarised in Figure 1, above. They are valued at the rate of the annual timber rent values developed by Statistics Canada (2000) on the basis of timber harvested. These are a part of Statistics Canada's monetary timber asset account.

Fig.4. Alberta Forest Industries: GDP, NDP, EDP (Stock Changes)
[$Millions, 1992]



Thus EDP based on timber stock change, as shown in Figure 4, combines information from two distinct data sources, i.e. Statistics Canada's physical and monetary timber accounts. As outlined in Chapter 7, above, the monetary account is based strictly on timber harvested. The physical account was developed independently, from forest resource inventories, using simulations of growth and various sources of depletion. Only harvested timber has been valued by Statistics Canada. The physical stock changes due to fire loss, mortality, road construction, and regeneration have not.

Consequently, the application of timber rent to all stock changes needs some qualification. The two accounts describe essentially the same land base: that portion of forest land where commercial timber production is viable (about 35% of Canada's total forest land). However, the value of the timber harvested is not strictly applicable to the stock changes due to other causes. For example, it should not be assumed that timber burned, and lost to other natural causes, had the same value as that harvested. As well, forest land where regeneration is taking place may not have timber of merchantable size. Other studies have applied lower values (e.g. one half) to stock changes due to deforestation and regeneration in secondary forests, than to those due to harvest (Repetto, Magrath, Wells, Beer, & Rossini, 1989). Figure 4, then, offers a rough approximation of the value of all changes to the timber stock.

Figure 4 again reflects what is clear from Figure 1, namely that the volume of timber harvested has increased steadily since 1961, to the point of outweighing forest regeneration by the mid 1990s. Consequently, EDP based on changes in timber stock is mostly greater than NDP until that time: only since the startup of new mills in the 1980s and early 1990s does the

physical timber account consistently indicate net depletion of the timber resource. This might be taken as an optimistic description of the impact of Alberta's forest industries, given that forest regeneration has probably been overvalued, as noted in the previous paragraph.

Another outcome of considering all timber stock changes in value terms should be kept in mind. In contrast to Figure 1, Figure 4 shows changes in timber stock weighted by current price. For example, the depletions due to fire and harvest in 1995 are relatively heavily weighted by high prices for forest products in 1995: depletion due to fire in 1980 to 1982 is relatively lightly weighted. These price variations reflect the forest business cycle rather than underlying resource scarcity.

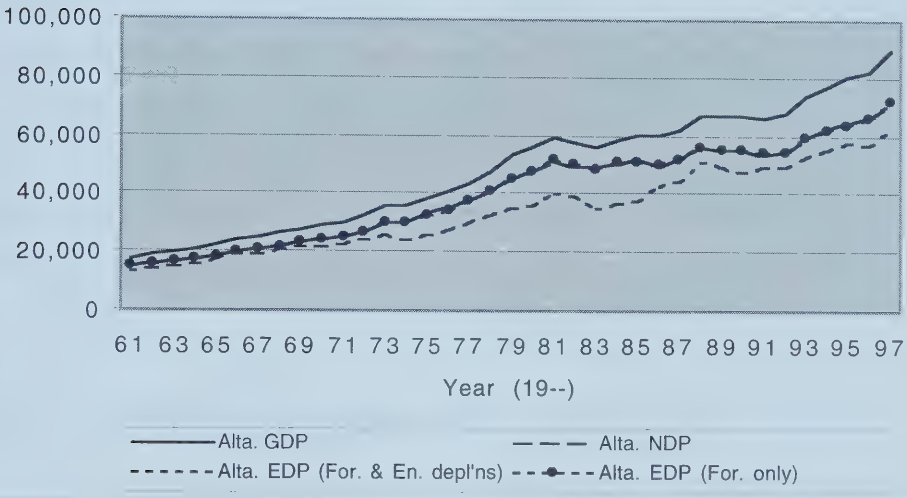
8.4 ALBERTA ECONOMY: EDP

In this section, some perspective on the forest sector within Alberta's economy is provided. By 1997, Alberta's forest sector had grown to the point of generating 2.1% of the province's GDP. At that time, the energy sector, which will be discussed further below, produced 19.2% of Alberta's income, thus outweighing forestry by almost a factor of ten.

Figure 5 presents GDP and NDP for the entire Alberta economy, with EDP showing income adjustments for depletions of both energy resources (crude oil, natural gas and crude bitumen) and the timber resource. Adjustments for timber depletion alone are also shown. Depletions here are total depletions due to energy extraction and timber harvest, as opposed to net depletions, which would also reflect new discoveries in energy and, for example, regenerating timber. While the adjustments for

depletion of energy resources are substantial in terms of the province's economy (over 20% of GDP at times), the adjustments for timber depletion are much smaller.

Fig.5. Alberta GDP, NDP, EDP (Forestry & Energy Depletions)
[$Millions, 1992]



8.5 ALBERTA ENERGY INDUSTRY

The history of the world oil market since 1961 is characterised by dramatic price increases in 1973-5 and 1979, resulting from production capacity constraints and cartelisation by OPEC. The elasticity of both supply and demand proved higher in the longer term, and these price shocks were followed by successful exploration and conservation. In particular, the rent gaps resulting from the high prices allowed higher-cost discoveries, which eventually resulted in increased supply and lower prices. Prices fell dramatically in the mid 1980s. In the long term, real oil

prices have not increased: world oil prices in 1995 were about the same as in 1972 (Hartwick and Olewiler, 1998).

These events in the world oil market had strong impacts on Alberta's economy. Most obviously, the high price of oil in 1980, and the fall in price in the mid 1980s are clearly evident in energy sector GDP in Figures 6 and 7, below. Energy contributed 36.7% of Alberta's GDP in 1984, but this had declined to 15.6% by 1991. This is in spite of the fact that these figures incorporate values for natural gas, whose price has been insulated from world prices until recently, as well as crude oil and crude bitumen. Hartwick and Olewiler (1998) note that bitumen has functioned as a backstop to crude oil.

8.6 ALBERTA ENERGY INDUSTRY: EDP

Figures 6, 7 and 8 present GDP, NDP and EDP for Alberta's energy sector. As in the case of forestry, above, the adjustments for depreciation of man-made capital are not truly specific to the industry: they are the energy sector's share of depreciation of man-made capital, based on its share of the province's GDP.

These three figures represent each of three possible ways of calculating EDP. In Figure 6, income is adjusted to reflect only energy resource depletion. Extraction, but not new discoveries, of crude oil, natural gas and crude bitumen is accounted for. Figure 7 presents net depletion of energy resources, i.e. extraction net of discoveries. Here, all the known physical changes to the resource base are netted from conventional NDP. Figure 8 also encompasses both positive and negative

stock changes. As well, it incorporates as current income the changes in value of the entire resource stock due to price changes.

Figure 6, again, presents energy sector income adjusted only for depletion of energy resources. The question of whether energy EDP should be measured by total or net depletions will be returned to below. At this point, simply note that there is a certain logic to the approach taken in Figure 6. Total depletions, are, in one sense, a truer representation of our impacts on the resource, since we do not, physically, add new discoveries: they were already there.

Fig.6. Alberta Energy Industry: GDP, NDP, EDP (Depletions)
[$Millions, 1992]

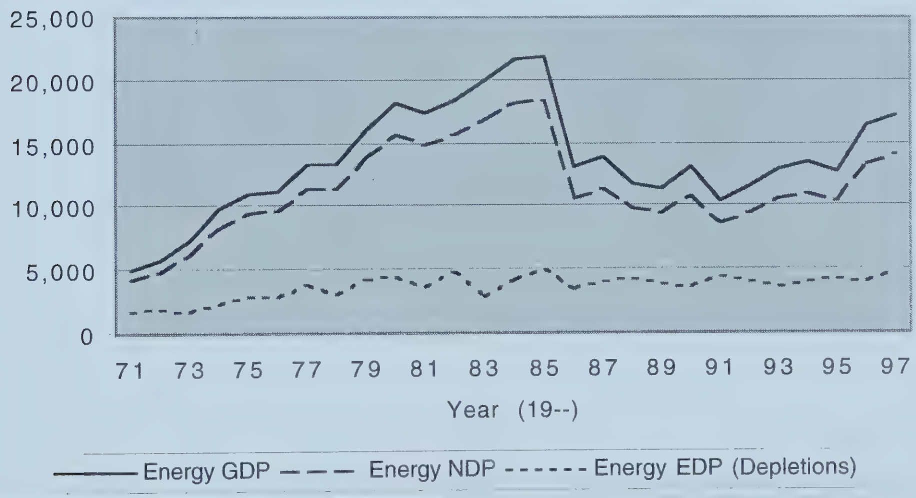
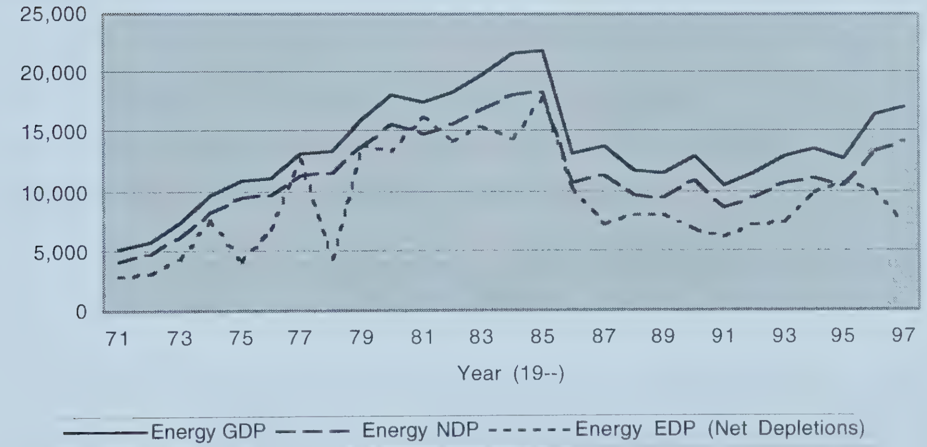


Figure 6 indicates that, if only depletion of energy resources is accounted for, EDP has gradually increased since 1971, indicating that the sector, viewed in isolation, was sustainable. Note, however, that this adjustment reduces the sector's income by at least one half. EDP was

much less variable over time than GDP, since the value of depletions was always roughly proportional to conventional sector income.

Figure 7 presents energy sector EDP based on net depletions, i.e. all changes in the stocks of energy resources. It is clear from Figure 7 that, in general, much more energy was extracted than discovered between 1971 and 1997. One exception to this was in 1985-86, at the time when world oil prices fell dramatically.

Fig.7. Alberta Energy Industry: GDP, NDP, EDP (Net Depletions)
[$Millions, 1992]

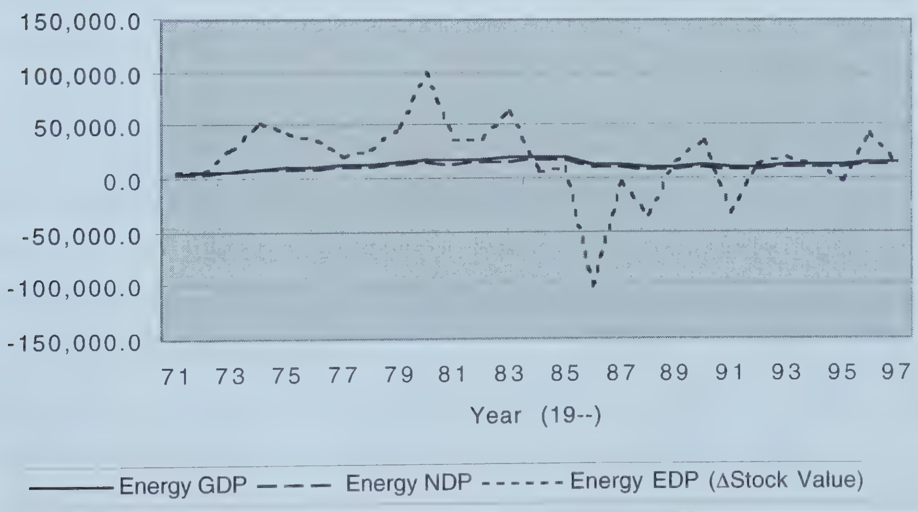


Unlike Figure 6, Figure 7 includes, as income, capital gains due to discoveries of new energy resources. It does not include capital gains arising from terms of trade effects, or due to price changes on unextracted reserves (see Figure 8, below). Unrealised capital gains from price changes on reserves are excluded here for consistency with the asset-accounting practices applied to man-made capital. In Canada's national

income accounts, most business plant and equipment is depreciated, not on the basis of replacement cost, but on the basis of its original book value, amortised over its life (Statistics Canada, n.d.). For this reason, GNP and NNP run parallel. This approach, where EDP is based on net depletion of natural capital, also has the advantage that information on stock changes is better than that on total stocks (Repetto, Magrath, Wells, Beer, & Rossini, 1989).

In Figure 8, EDP includes capital gains due to both energy discoveries, as in Figure 7, and due to revaluations of unmined stocks resulting from price changes. Since, for energy, the price elasticities of demand and supply are low in the short run, prices are subject to large fluctuations over short periods of time. Consequently, in an energy-resource-dependent economy, including the unrealised capital gains from price changes in current income tends to lead to large swings in income (Repetto, Magrath, Wells, Beer, & Rossini, 1989).

Fig.8. Alberta Energy Industry: GDP, NDP, EDP (Stock Value Change) [$Millions, 1992]



This treatment of unrealised capital gains and losses due to price changes is consistent with a Hicksian definition of income. A year's capital gain could be consumed without reducing future potential consumption to a lower level than at the initial price level (Repetto, Magrath, Wells, Beer, & Rossini, 1989). Brekke (1997) and Vincent, Panayotou, and Hartwick (1997), however, advise caution in the use of Hicksian income in a context with uncertainty, such as that surrounding energy prices. Had oil-producing economies, such as those of Norway and Indonesia, consumed their entire Hicksian income during the 1970s, they would have gone into debt when oil prices fell in the mid 1980s. The decline of oil prices in the long run implies that some of this Hicksian income should have been invested.

The applicability of these cautions to Alberta can be clearly seen in Figure 8. In Figure 8, the effects of price changes swamp the effects of stock changes, which are more evident in Figures 6 and 7. Positive price changes generated large unrealised capital gains prior to the mid 1980s, but these were followed by large unrealised capital losses when prices fell, particularly in 1986.

Repetto, Magrath, Wells, Beer, and Rossini (1989) make the additional point that the dramatic fluctuations we have seen in energy prices have also had strong effects on the value of man-made capital. For example, the price shocks of the 1970s made older industrial equipment economically worthless, since it could not be operated at a profit at high energy prices. Drastic inflation also occurred in real estate markets in oil-producing areas. However, income accounts do not reflect these

fluctuations, since, as noted above, much of this capital is depreciated based on book value, not on the basis of lost future income.

8.7 ALBERTA FOREST AND ENERGY INDUSTRIES: PEARCE ATKINSON MEASURE

The preceding section covered the implementation of income adjustments to reflect the depletion of forest and energy resources. The same kind of adjustment applied to investment measures often provides more insight into an economy, since investment flows are smaller than income flows. Consequently, the adjustments are larger in proportion to the total (Smith, 1992; World Bank, 1995). In this section, then, Alberta's net saving is adjusted for depletion of the province's forest and energy resource assets. This provides an estimate of the Pearce-Atkinson measure for Alberta.

Table 1 (next page) presents the data used in the calculation of the Pearce-Atkinson measure (PAM). Values for PAM and its components are presented for Alberta for the period from 1967 to 1996.

The starting point for the calculation of PAM is gross saving. This is the conventional measure of a nation's rate of accumulation of capital. Gross saving is calculated as the residual of GNP minus public and private consumption. It represents the total produced output set aside for the future, either as foreign lending or as domestic investment. This measure of aggregate saving is adjusted for depreciation of produced assets, giving net saving. Finally, adjustment is made for the value of changes to the

natural resource base, accounting for depreciation (or appreciation) of natural capital. This gives PAM (World Bank, 1997).

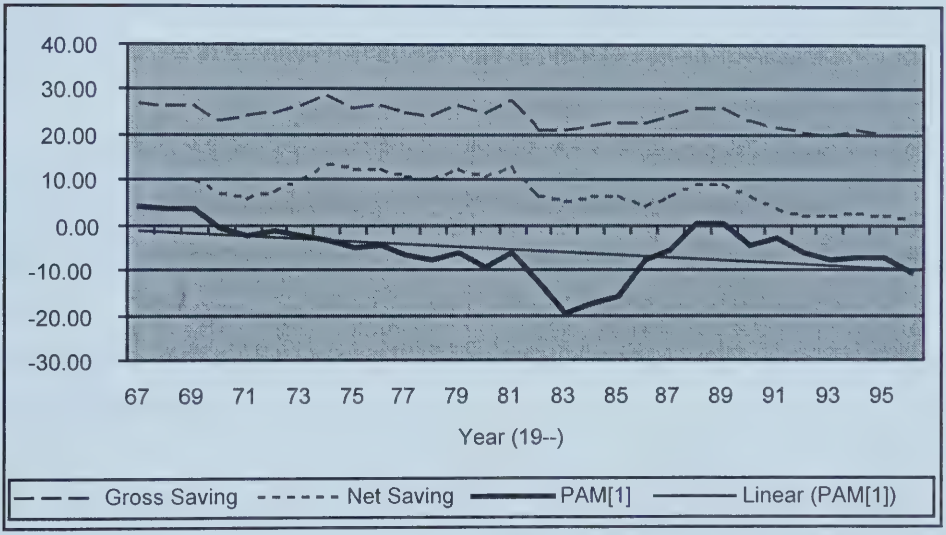
Table 1. Pearce-Atkinson Measure of Weak Sustainability for the Alberta Economy [as % of GDP]

			PAM - Depletions			PAM - Net Depletions		
Year	Gross Saving	Net Saving	Forest Depl'n	Energy Depl'n	PAM_1	Forest Net Depl'n	Energy Net Depl'n	PAM_2
1967	27.15	10.43	0.16	5.92	4.35	-0.97	-9.58	20.97
1968	26.17	9.90	0.15	5.96	3.79	-0.75	-13.24	23.89
1969	26.48	10.35	0.16	6.33	3.86	-0.71	-2.70	13.76
1970	22.98	6.85	0.15	7.30	-0.59	-0.62	1.58	5.89
1971	24.04	5.94	0.17	7.82	-2.06	-0.76	4.17	2.53
1972	24.67	7.48	0.23	8.69	-1.44	-0.77	5.58	2.67
1973	26.31	10.26	0.29	12.36	-2.39	-0.86	4.83	6.29
1974	28.44	13.64	0.26	16.66	-3.29	-0.88	1.68	12.85
1975	25.98	12.23	0.15	16.95	-4.86	-0.53	13.73	-0.97
1976	26.27	12.23	0.12	16.77	-4.67	-0.36	6.92	5.67
1977	24.79	10.68	0.12	17.07	-6.51	-0.31	-3.30	14.28
1978	24.38	10.29	0.17	17.69	-7.57	-0.43	15.10	-4.38
1979	26.20	12.54	0.14	18.31	-5.91	-0.20	0.31	12.43
1980	24.87	10.75	0.04	20.09	-9.38	0.04	3.89	6.83
1981	27.28	12.71	0.02	18.85	-6.15	0.07	-2.42	15.06
1982	21.25	6.37	-0.02	18.85	-12.46	-0.02	2.43	3.97
1983	20.81	5.53	0.03	24.94	-19.44	-0.06	2.28	3.31
1984	22.04	6.54	0.07	23.82	-17.35	-0.09	6.32	0.31
1985	22.39	6.45	0.03	22.05	-15.63	-0.05	0.70	5.80
1986	22.86	4.25	0.04	12.02	-7.81	-0.06	0.80	3.51
1987	24.01	6.22	0.15	11.79	-5.72	-0.19	6.74	-0.32
1988	25.75	9.01	0.21	8.24	0.56	-0.16	2.58	6.59
1989	26.09	9.14	0.06	8.53	0.55	-0.05	2.22	6.96
1990	23.20	6.21	0.11	10.74	-4.63	-0.08	5.90	0.39
1991	21.33	3.58	-0.02	6.35	-2.75	0.01	3.77	-0.21
1992	20.20	1.94	0.05	7.81	-5.93	-0.03	3.32	-1.36
1993	20.13	1.91	0.20	9.42	-7.72	-0.08	4.46	-2.48
1994	21.00	2.49	0.67	9.12	-7.29	-0.02	1.53	0.98
1995	20.15	1.78	1.27	7.60	-7.09	0.64	-0.23	1.37
1996	19.70	1.42	0.73	11.29	-10.60	0.02	4.16	-2.77

[Sources: Gross Saving: Statistics Canada (1970...1999)
Capital Consumption Allowance: Alberta Treasury (1990...1999)
Natural Capital Depletion: Statistics Canada (2000)

Figure 9 presents PAM based on resource depletion (PAM_1). The values deducted for forestry are for timber harvested (as in Figure 3, above), and those deducted for energy are for crude oil, crude bitumen and natural gas extracted (as in Figure 6, above). Forest regeneration and discoveries of new energy reserves are not accounted for here.

Fig.9. PAM_1, Forestry and Energy Depletions [as % of GDP]



Gross savings (based on Canada's savings rate) fell from 27% of GDP to 20% between 1967 and 1996. More specifically, gross savings dropped at the time of the recession in 1982-3, and largely recovered throughout the 1980s. They fell again at the time of the 1990 recession, and did not rebuild between then and 1996. Depreciation of produced capital demonstrated an increase of 1-2% of GDP between 1967 and 1996, suggesting a modest increase in industrialisation. The combined effect of

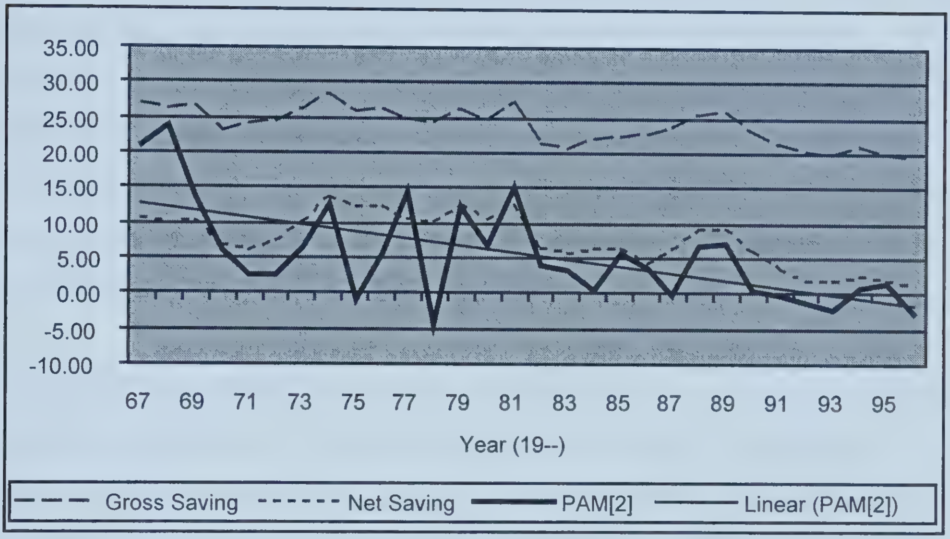
these trends in gross saving and produced capital depreciation is that net savings fell slightly more than gross savings, reaching a level of only 1.4% of GDP by 1996. Thus the conventional measure of investment, corrected for depreciation of man-made capital, fell almost to zero by the late 1990s.

When depletion of forest and energy resources is factored in, this picture changes substantially. Over the period studied, an additional 6% of GDP (in 1967), increasing to over 9% (by the mid-1990s) of asset depletion becomes evident. In particular, between 1981 and 1987, adjusting for resource depletion lowers investment by as much as 25% of GDP.

As in the case of the income adjustments above, the depletion of energy resources far outweighs the depletion of forest resources. Only since 1993 has forest depletion grown to a level exceeding 6% of energy depletion. The highest levels of natural resource asset depletion (and lowest PAM_1 levels), between 1981 and 1987, reflect high world oil prices during that period.

Figure 10 presents PAM based on net resource depletion (PAM_2). The adjustments here are the same as the income adjustments in Figure 4 (forestry) and Figure 7 (energy). Net forest depletion is quantified as all physical changes to the stock of standing timber, valued at timber rent. Net energy depletion is crude oil, crude bitumen and natural gas extracted, net of discoveries.

Fig.10. PAM_2, Forestry and Energy Net Depletions
[as % of GDP]



Except prior to 1970, extraction of energy resources has consistently outweighed discoveries. Even when viewed in terms of net depletion, then, the energy sector contributes significant disinvestment to Alberta's natural capital stocks. PAM followed a downward trend over the period studied, whether calculated on the basis of total depletions or net depletions. PAM_1, based on total depletions, fell to -6% to -10% of GDP by the early 1990s: PAM_2, based on net depletions, fell to close to zero.

World Bank researchers have generated values of PAM (genuine savings) for a variety of countries. A common trend evident in this work is that measurement of PAM depresses savings in resource-rich countries (Atkinson et al., 1997). This tendency prevails across the spectrum from developing countries (e.g. Sub-Saharan Africa) to high-income OECD countries (United Kingdom, Norway).

For Sub-Saharan Africa, World Bank estimates of PAM suggest that the more resource-rich countries in the region have been the worst dissavers. Developing countries with rich resource endowments have tended to do poorly as a result of depending heavily on their resources, and underinvesting. PAM in this region started to fall dramatically around 1980, following the second oil price shock, as some of the larger nations went into debt (World Bank, 1997; Atkinson et al., 1997).

Also worth noting for their historical similarities to Alberta are the oil-exporting countries of the Middle East and North Africa. World Bank analyses show negative PAM values for many of these. The high oil rents of 1978-79 contributed to significant investment; nonetheless their overall effect on saving was negative. Surpluses became deficits in several of these countries, as consumption soared and imports flowed. PAM improved for the region in the early 1980s, but remained below zero (World Bank, 1997).

World Bank estimates of PAM for high-income OECD countries suggest that these countries, also, have failed to convert sufficient of their resource rents to investment. While PAM for these nations is relatively stable, those engaged in more resource extraction, including Canada, have noticably lower levels of PAM (1-3%, as opposed to about 10%) (World Bank, 1997). Norway and the United Kingdom both share Alberta's experience of low levels of PAM (based on total depletion) in the early 1980s, when oil prices were high. As in Alberta, PAM for both Norway and the United Kingdom recovered in the late 1980s, when oil prices dropped again (Atkinson et al., 1997).

8.8 DISCUSSION

This chapter has presented empirical results for several approaches to the implementation of EDP and PAM. The most important of these involve adjustment of conventional accounting aggregates for two versions of natural resource depletion: total depletion and net depletion. No clear consensus exists as to which of these gives the better measure of sustainability.

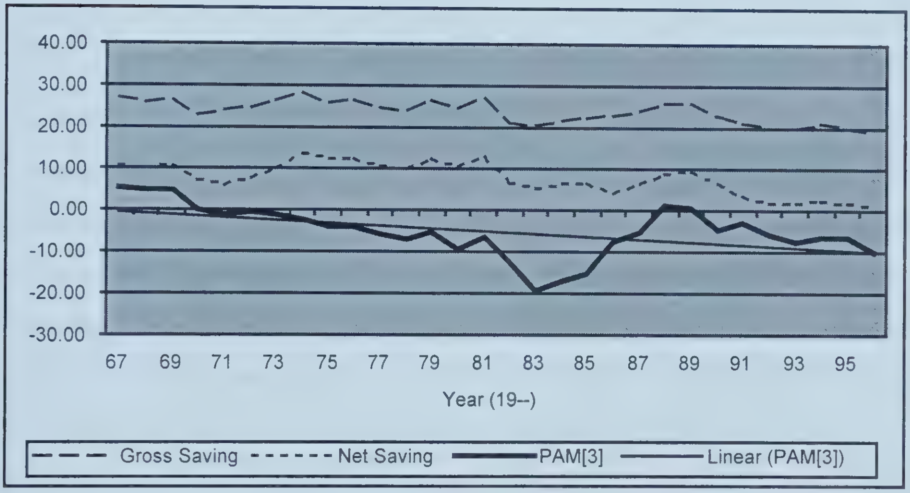
In the case of nonrenewable resources, World Bank researchers have argued in favour of adjusting both income (to give EDP) and investment (to give PAM) by the value of total depletion. The main reason given for not netting out new discoveries is that most exploration expenditures are already recorded in the conventional accounts as investment. Admittedly such exploration expenditures are more an approximation of average discovery costs than of marginal discovery costs. Nonetheless their inclusion is taken to account for the value of new discoveries (Atkinson et al., 1997; World Bank, 1997).

For forest resources, the same authors favour adjusting income and investment measures by the value of net depletion of commercial species. Forest depletion, then, is quantified as the volume by which harvest exceeds growth, both harvest and growth being valued at the current rental rate. Should growth exceed harvest, then net growth should be added to NNP, and to investment measures (Atkinson et al., 1997; World Bank, 1997).

Application of the criteria suggested by World Bank researchers in our analysis of resource depletion in Alberta gives Figure 11. Here, net

saving is adjusted for total depletion of energy resources, and for net depetion of forest resources, to give PAM_3. Again, of course, the adjustments for forestry are heavily outweighed by those for energy.

Fig.11. PAM_3, Forestry Net Depletions and Energy Depletions
[as % of GDP]



As described above, World Bank research has found that oil-producing countries throughout the world tend to be dissavers, based on PAM. This result arises partly from the fact that resource rents were not discounted in the valuation of depletion. This valuation of depletion is theoretically correct, given the assumption of an efficient time path for resource rents, i.e. the Hotelling rule. Under this assumption, current production causes a change in the present value of the reserve (user cost) equal to the rent, as net price, on that production. However, if efficient resource pricing is not assumed, then resource depletion should be valued using a non-zero discount rate (Atkinson et al., 1997).

For countries with long-lived oil deposits, even a low discount rate will yield user costs that are much lower than current rents. This has the implication that, where reserves are large, much less than resource rent needs to be reinvested in order to maintain the value of capital. To take an extreme example, using a discount rate of 3%, the user cost of resource extraction for Iran has been calculated at 3% of current rents (Atkinson et al., 1997).

Since empirical evidence for efficient resource rents is lacking (Adelman, 1990, as cited in Atkinson et al., 1997), it is arguable that rents should be subject to some level of discounting. Given Alberta's very large deposits of energy resources, the issue is certainly relevant to this study. As one example, Alberta's oilsands, estimated to contain 400 billion cubic metres of bitumen, represent a significant volume in terms of world reserves (Avery, 2001). This is a case in Alberta's context where, potentially, discounting could have a big impact on valuation. Only 661 million cubic metres (0.2%) of Alberta's oilsands were classified as commercially accessible in 1997 (Statistics Canada, 1997). Clearly, the true user cost of extraction is very sensitive to the question of how much of the reserve is close to being recoverable economically.

Some discounting was used in the development of the energy resource values in this thesis. These values come from a combination of a net price calculation and a present value calculation (using a discount rate of 4%). This procedure is outlined in Chapter 7, above, and in Appendix 1, Part C. The reserves included in these calculations are limited to economic reserves. These are defined as those known to exist with a high degree of geological certainty, and economically viable under current market and technical conditions (Statistics Canada, 1997). For Alberta's energy

resources, the discounting applied has often reduced the net price calculation of stock value by about one half, but seldom by much more (Statistics Canada, 2000). If, for example, a less conservative estimate of Alberta's bitumen reserves were used, discounting would further reduce the value of depletions. Given recent progress in oilsands recovery technology, (J. D. Scott, personal communication, 8 June, 2001) it is quite possible that a less conservative estimate would be appropriate.

This brings us back to the problem of identifying the best possible measure of sustainability for Alberta, based on resource depletion data. PAM_3, above, is based on the approach suggested by World Bank researchers, with the difference that PAM_3 does incorporate some discounting into the valuation of energy resources. The problem of overvaluing energy resource depletion, by not discounting, is thus at least partially addressed in PAM_3. PAM_3, then, is taken as our best measure of investment, adjusted for resource depletion, for Alberta.

8.8.1 Formal Interpretation of EDP and PAM for Alberta

For the reasons identified above, forest EDP based on net timber depletions (Figure 4, above) is taken as our measure of sustainable forest income. Our estimate of sustainable income for the energy sector is based on total energy depletions, as shown in Figure 6. Sustainable income for the provincial economy is shown in Figure 5 (ideally, Figure 5 would show net forest depletions rather than depletion due to harvest, but the difference between these two is small in the context of Alberta's economy).

As described in Chapter 6, above, under certain assumptions, the basic interpretation of EDP, regarding sustainability, is that the economy is

on a sustainable path if EDP increases over time. Forest EDP (Figure 4) decreased slightly between 1971 and 1982, then increased substantially over the period from 1981 to 1997. Over the entire time period studied, forest EDP increased, indicating sustainability, but it reflects significantly less growth than forest GDP. It must be kept in mind that only timber values were accounted for here. Other forest values are discussed further below.

Energy EDP (Figure 6) also increases over the period studied, indicating sustainability in the sector. Overall, its growth was less than GDP growth, and very much weaker than GDP growth until 1986, when oil prices dropped. In the energy sector, accounting for depletion of natural capital reduces income by more than it does for the forestry sector.

The provincial economy (Figure 5) shows increasing EDP, again indicating sustainability. This increase in EDP was consistent except for a drop in 1982-83, and a smaller fall in 1988-90.

The formal interpretation of PAM is that a time path where investment net of resource depletion (i.e. PAM) is consistently negative is not sustainable. Atkinson et al. (1997) identify PAM as a one-sided sustainability indicator, in that non-negative PAM, at any point in time, may or may not indicate sustainability. However, consistent dissaving can be shown, unequivocally, to lead to non-sustainability.

As discussed above, PAM for Alberta, based on total energy depletions, was negative except very early in the 1967-1996 study period, and decreased faster than gross savings (see PAM_3, Figure 11). The basic interpretation of this is that Alberta's pattern of investment has become unsustainable, when changes in the natural capital stock are considered

(see caveat below, relating to the savings rate used). Even if based on net energy depletions (PAM_2, above), which, arguably, double counts discoveries, PAM has become negative by the early 1990s.

The outcome of positive net savings, but negative PAM, implies that future well-being is less secure than we knew on the basis of conventional investment measures. Eventually, policies leading to negative savings rates, as shown here with PAM values for Alberta, will entail declining welfare (World Bank, 1997). In this analysis of Alberta's economy, the value of resource depletion does not appear as reinvestment: gross savings do not reflect enough investment to compensate for natural resources extracted. Thus when sales of natural resource assets are distinguished from wealth creation, it becomes evident that disinvestment has occurred. This combination of resource depletion (asset sales) and low gross savings results in persistently negative PAM values, with the implication that part of the province's wealth was consumed.

It bears emphasising here that the gross savings data used - Canada's gross savings rate, not Alberta's - constitute a weak link in this analysis. If Alberta's savings rate is, in fact, substantially higher than Canada's (necessarily about 7% higher by the early 1990s), then the conclusion of nonsustainability is not valid. To the extent that Canada's savings rate does reflect saving in Alberta, these results indicate that Alberta has failed to convert sufficient of its resource rents to investment.

8.8.2 Interpretation of EDP and PAM Together

If measurement were perfect, one might expect to see decreasing EDP at the same time as negative PAM, both being signals of

nonsustainability. This is not evident in our results. Realistically, with technological change unaccounted for, and given the varying levels of productivity of the different types of capital in the economy, it probably should not be expected. A more inclusive analysis than this one might show more consistency between measures of EDP and PAM. If, for example, it were possible to accurately account for human capital, as well as man-made and natural capital, then trends in EDP and PAM might correlate more closely.

World Bank researchers have suggested that PAM measurement can provide explanations for changes in income over time (World Bank, 1995). For example, PAM (genuine savings) for Sub-Saharan Africa fell dramatically around 1980: this correlates with a drop in GDP growth rates in the region (World Bank, 1997).

This much consistency is also evident between our EDP and PAM measures for Alberta. In 1982-83, EDP (Figure 5) falls at about the same time as PAM_3 (Figure 11) becomes strongly negative. However, this does not necessarily reflect a direct causation between erosion of the capital stock and negative income growth. Rather, it is likely that PAM and EDP both fell at this time as a result of the recession, which clearly affected PAM through gross savings (see Figure 11). PAM continued to fall subsequently, as a result of the high price of oil until 1986.

This PAM analysis indicates that a part of Alberta's asset base has been consumed, rather than offsetting reinvestments being made (although the caveat above concerning the savings rate used must be kept in mind). How, then, has Alberta's economy been able to continue to grow, as evidenced by increasing EDP? One reason was alluded to at the start of

this section: the combination of the empirical results for EDP and PAM suggests that technological change and human capital have been strong factors in the province's economy.

Other reasons are possible for the conflicting messages from EDP and PAM with respect to sustainability. If foreign direct investment is higher in Alberta than throughout Canada, then Canada's savings rate will underestimate savings in Alberta. As with human capital and technology, growth from such investment will be reflected in EDP, while the investment itself is not reflected in PAM. As well, EDP will have grown in response to population growth: PAM, calculated for each year as a ratio of investment to income, is effectively adjusted for population growth. Finally, savings may have been higher in Alberta than in Canada, during the period studied, as a result of Alberta Heritage Savings Trust Fund (AHSTF) investments.

It should also be noted that technological change has effected a strong flow of energy discoveries during the period studied (J. D. Scott, personal communication, 8 June, 2001). Improvements in energy extraction technology have made many previously inaccessible reserves economically viable. As shown in Figure 10, discoveries of energy resources have continued to substantially offset extraction. Consequently, there is still no strong sense of resource scarcity in Alberta. The picture that emerges from our PAM analysis is that substantial erosion of the natural capital base, particularly in the form of energy resources, has taken place. However, technological developments have enabled extraction to continue at an increasing rate, in physical terms (Statistics Canada, 2000). This confuses the picture: the limit of our nonrenewable natural resources is a moving target. As long as discoveries effectively offset extraction, and

asset sales are not accounted for as such, the province may be able to dissipate the asset without apparent consequence. However, this cannot be expected to continue indefinitely.

The important point is that an opportunity to build for the future was apparently not fully utilised, on the evidence of this PAM analysis. For all that EDP continues to show growth, up to 24% of GDP has been taken from the economy in the form of natural resources, each year. Conventional measures of investment do not indicate that this amount was reinvested (although the above qualification concerning the savings rate still applies). Instead, more of the windfall of high energy rents, particularly in the early to mid 1980s, could have been invested to ensure future opportunities. It is in this sense that an opportunity was missed. This is not altered by the fact that no definite end to Alberta's natural resources is yet in sight, and the economy continues to grow.

The consequences of failing to invest the proceeds of natural resource sales are partially illustrated by events that have already taken place in Alberta's economy. Alberta's provincial and municipal governments spent 25-75% more per capita than other provinces in the late 1970s and early 1980s, as well as taxing at much lower rates (Smith, 1992). This created expectations which could not be met at lower energy prices, and the resulting reduced resource revenues. After the price of oil fell in 1986, the provincial government had to raise taxes and strictly control expenditure increases. This situation could have been eased had more investment taken place when energy revenues were high (Smith, 1992).

This is not to say that the Alberta government failed to make any investments with its energy revenues. Investments have been made in

public infrastructure, and in various types of assets through heritage fund investments. Substantial expenditures were made on education and health care: in these areas, it is particularly difficult to differentiate consumption and investment (Smith, 1992). In the PAM analysis in this thesis, it is likely that some investment in human capital was not fully captured in gross savings.

8.8.3 Level of Aggregation

It is open to question whether it is entirely meaningful to analyse the sustainability of Alberta's resource base as if Alberta's were a closed economy. People migrate freely within Canada, and natural resources are traded within Canada and internationally. Resource depletion is therefore a global issue. Consequently, the province of Alberta represents a relatively low level of aggregation at which to address questions of the sustainability of resource depletion. Transboundary pollution presents further questions, which are not addressed here, since this thesis does not quantify environmental degradation.

To date, little has been done to establish a conceptual framework to handle these questions. World Bank researchers identify the key question as that of whether it is necessary for measures of sustainability to reflect trade flows of natural resources (Atkinson et al., 1997). Some theoretical analysis, using green accounting models, has been made of international trade and sustainability (Asheim, 1986 and Hartwick, 1994, as cited in Atkinson et al., 1997). Where resource exporters were modelled as price takers, savings requirements for sustainability were found to be the same as those implied by the Hartwick rule for a closed economy. World Bank researchers have inferred from this that, since individual countries are

generally price takers in international resource trade, resource-extracting countries should reinvest resource rents, whether the resource is exported or not (Atkinson et al., 1997). For sustainability, it is argued, each country, developed or otherwise, resource exporter or otherwise, is responsible for prudent management of its assets.

8.8.4 Perspective on Forestry

The values of EDP and PAM developed here for Alberta are driven primarily by what happens in the energy sector. Consequently, this analysis of EDP and PAM has necessarily emphasised events in the energy sector. “Greening” the provincial accounts for depletion of natural capital involves much larger adjustments for energy than for forestry.

However, by the end of the study period (1997), the forest sector became a significant contributor to natural capital depletion. Timber harvest volumes, by that time, had closely approached regeneration volumes. Timber stock levels had started to fall. Forest depletion due to harvesting reached a level valued at 10% of the value of energy depletions in 1996 and 1997 (Statistics Canada, 2000).

It should be emphasised here that the adjustments to income and investment in this thesis are partial. This is particularly significant in the forest sector. The adjustments made for the forest industry comprise only the market value of timber harvested (EDP_1). It is likely that non-timber values (giving EDP_2, when combined with timber values) outweigh timber values (Costanza et al., 1997; Costanza, 2000b). If the value of environmental degradation associated with forest harvesting were accounted for in Alberta, as well as timber values, the adjustments for the

forest sector would contribute a considerably higher proportion of the natural capital adjustments in this thesis.

CHAPTER 9: CONCLUSIONS

9.1 BACKGROUND

This research has constructed two macroeconomic indicators of sustainability, environmentally-adjusted income (EDP) and the Pearce-Atkinson measure (PAM). These are based on adjustments to Alberta's income and investment measures for natural resource extraction by two major resource extraction industries, energy and forestry. The adjustments take into account natural resource depletion by these industries, but not environmental damage. The value of the forest as a source of timber is included, but not its value as, for example, wildlife habitat or a regulator of climate. Thus the study estimates EDP_1, but does not extend to EDP_2 (defined in Chapter 6). It addresses questions of excessive resource depletion, but not questions of environmental degradation.

This thesis has worked from the premise that the conditions for achieving sustainability may be defined, for operational purposes, in terms of expanding the capital stock. Capital was defined broadly: it was taken to include natural, human, and social, as well as man-made capital. Sustainable income was taken to be that amount that can be consumed without diminishing the capital stock. These concepts are the basis for the indicators implemented in this thesis. EDP, our measure of sustainable income, was estimated by adjusting provincial income for depletion of natural capital. PAM was estimated by adjusting standard measures of investment flows for natural capital depletion. These partial adjustments for natural capital are the first steps toward quantifying sustainability in the paradigm adopted. Human and social capital are much harder to quantify than natural capital, and are not accounted for in this study.

9.2 WHAT THE INDICATORS SAY

EDP for the forest and energy sectors (1971-1997), and for Alberta (1961-1997), increased over the period studied. This indicates sustainability in both sectors, and in the province as a whole. In all cases, but particularly for the energy sector, prior to 1986, EDP showed less growth than GDP. These results imply that, even when income is adjusted for disinvestment in natural capital, sufficient investment has taken place to enable the economy to grow.

PAM provides a rough, first-pass evaluation of investment adjusted for resource depletion. Empirically, for Alberta, PAM shows that investment, as measured conventionally, is not sufficient to offset the value of disinvestment in natural capital. Subject to the caveats noted below, this has the implication that insufficient of Alberta's natural resource rents were converted to investment. In other words, the proceeds from the sales of natural resource assets were, largely, consumed. An opportunity to invest for future generations may have been missed. However, as stated below, the accuracy of the savings rate used is critical to the outcome of the PAM analysis. As well, human capital formation, and technological change associated with capital formation, contribute to the level and growth of productive capacity. These were not considered in this analysis.

At a first glance, the finding that economic growth (EDP growth) continues, in spite of the evidence of PAM that capital stocks have been eroded, might be seen as undercutting the claim that decreasing capital stocks imply nonsustainability. Of four types of capital defined in Chapter 3, above, this analysis has effectively been limited to two, i.e. man-made

capital and natural capital. Preliminary estimates by World Bank researchers indicate that high-income countries hold 67% of their wealth as human capital, as compared to 36% for developing countries that export raw materials (World Bank, 1995). This suggests that human capital, while not accounted for in this PAM analysis, is probably a strong driver of Alberta's economy. A PAM analysis that included human capital might be expected to show results more consistent with those found here for adjusted income, showing growth in EDP. It is likely that human capital, and the technological change embodied in human and man-made capital, are factors that have, effectively, offset the depletion of the combined stock of man-made and natural capital shown in PAM for Alberta. Thus, EDP was able to show growth even when PAM was negative. Several of the caveats below relate to the discrepancy between EDP and PAM. The important point remains that, particularly in the late 1970s and early 1980s, energy rents provided an opportunity to invest that was apparently not well utilised.

As well, technology has offset the depletion of natural capital in a very specific way, by making possible a strong flow of new discoveries of energy resources. Alberta's accessible stock of energy resources has constantly been revised upward over the period studied. As a result, the full consequences of depleting this resource have still not been met. A substantial energy reserve still exists in the ground, part of which has continued to be made accessible. The resulting stream of energy rents has, to some extent, made it possible to ignore the problem of energy depletion, while energy prices have been high. PAM_3, the "consensus" measure of PAM in this thesis, registers energy depletion, but not energy discoveries: however, discoveries have strongly affected the economy by sustaining the flow of energy rent. Whenever Alberta's accessible energy resources effectively become exhausted, and the flow of energy rent stops,

the balance between consumption and investment will be forced to shift toward investment.

9.3 LIMITATIONS AND CAVEATS

A major limitation of this work, then, is that technological change and human capital are not explicitly accounted for. This is a probable source of the inconsistency between EDP and PAM, whereby EDP indicates sustainability while PAM strongly suggests nonsustainability. Human capital is not captured in PAM, but income flowing from it is captured in EDP.

Other factors also relate to the conflicting messages from EDP and PAM regarding sustainability. Economic growth due to population growth is expressed in EDP, but factored out of PAM. Also, if foreign investment is higher in Alberta than in Canada, this will influence PAM and EDP asymmetrically, with Alberta's additional foreign investment influencing EDP, but not registering in PAM.

Again relating to technology and human capital, the effectiveness of investment varies. The productivity of the various forms of capital represented by gross savings is unknown. Thus the contribution of man-made capital to the province's productive capacity is not fully quantified. Our measure of investment (gross savings) is also incomplete in the accounting sense of not capturing all relevant investment in human capital, as noted in the previous paragraph. Education and health care, for example, are areas where it is difficult to differentiate between consumption and investment expenditures. Human capital has often been identified as a very productive area for investment (World Bank, 1995).

At the level of data availability, the use of gross savings data for Canada, rather than Alberta, is a weakness in the construction of PAM. It is possible, for example, that Alberta Heritage Savings Trust Fund (AHSTF) investments have contributed to a higher savings rate in Alberta. If investment in Alberta is, in fact, substantially higher than in Canada as a whole, then the interpretation of PAM as signalling nonsustainability is incorrect. However, even if investment in Alberta is actually high enough to make PAM non-negative, the downward trend of PAM over time remains a concern. This trend is driven by increased depletion of natural capital, for which our data are specific to Alberta, as well as by decreasing gross savings.

To date, the depletion of natural capital in the forest sector has played a much smaller role in the economy than that in the energy sector. Forestry, at the EDP_1 level, is less significant than energy, but growing rapidly. At the EDP_2 level, the various forms of environmental degradation associated with forest harvesting can be expected to make forestry more important relative to energy. The significance of the forest sector is likely to increase dramatically if the value of the forest for recreation, and in climate regulation and other ecosystem functions, is considered. To name a few of these, ultimately, the role of the forest as wildlife habitat, in erosion control and nutrient cycling, and in maintaining genetic resources should be accounted for.

9.4 EDP AND PAM AS INDICATORS

Like most economic indicators, EDP and PAM are indicators of weak sustainability. Unlimited substitution between man-made and natural

capital is assumed. The framework of these indicators is one that provides a mechanism for handling trade-offs between economic and biophysical elements, within the limits of our ability to value environmental change. However, the assumption of unlimited substitutability between natural and produced capital tends to lead to relatively optimistic judgments. This substitutability is largely denied in the ecological literature, particularly with respect to certain categories of natural capital (Pearce & Atkinson, 1995). Consequently, some sustainability concerns remain unaddressed. Critical elements of natural capital are not adequately handled in this framework. Our understanding of the connections between the different forms of capital needs to be improved. A need remains to develop indicators of strong sustainability.

This study of Alberta illustrates the need for resource accounting. A more comprehensive set of accounts is needed to allow an accurate portrayal of both the levels and growth rates of income and investment. The adjustments made here suggest that Alberta has spent an amount from natural resource revenues that was not consistent with maintaining its stock of natural and man-made capital. More complete accounts could give better guidance as to the appropriate split between consumption and investment.

9.5 FURTHER RESEARCH

The most important outstanding data requirement for development of this line of research is a better measure of investment for Alberta. Gross savings data specific to Alberta are needed.

As well, more work is needed to differentiate investment and consumption. For example, some expenditures which could properly be classified as investment are not so classified in existing accounts. Current expenditures on education are a case in point. World Bank researchers are now treating these as investment in their calculations of genuine saving (Hamilton, 2000). Certain expenditures on health and research should be viewed the same way. These steps would lead to an investment measure that is more inclusive with regards to human capital.

A logical step to extend this research would be inclusion of data quantifying environmental degradation. This equates to taking the step from EDP_1 to EDP_2, and making the corresponding adjustments to PAM. A substantial amount of work has been done in Alberta on non-market valuation. However, estimation of EDP_2 inheres valuation requirements well beyond what is currently feasible. Partial estimation of EDP_2, for example to the extent of estimating the value of CO_2 emissions, is feasible, and of interest given Alberta's dependence on energy production.

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APPENDIX 1: VALUATION OF NATURAL CAPITAL

This appendix presents the key equations of the methodology adopted by Statistics Canada for valuation of natural capital.

[Reference: Statistics Canada. (1997). Concepts, sources and methods of the Canadian system of environmental and resource accounts. Econnections: Linking the environment and the economy. Catalogue No. 16-505-GPE. Ottawa: Minister of Industry.]

A. Estimation of the cost of produced capital used in resource extraction

The cost of produced capital stock used in resource extraction is estimated by Statistics Canada as the sum of the return to produced capital, r_iK, and the annual level of depreciation, δ

$$C_K = r_iK + \delta$$

Definition of Symbols:

- δ = annual level of depreciation of the produced capital stock
- C_K = cost of produced capital
- K = produced capital stock, valued at replacement cost (measured at the end of each year as the sum of the industry's capital investments, net of accumulated depreciation)
- r_i = nominal long-term industrial bond rate

B. Estimation of resource rent

Lower bound estimate of resource rent

$$RR_I = TR - C - (r_iK + \delta)$$

Upper bound estimate of resource rent

$$RR_{II} = TR - C - \delta$$

Definition of Symbols:

δ = depreciation of the produced capital stock
C = annual non-capital extraction costs
K = produced capital stock value
RR_I = annual resource rent, lower bound
RR_{II} = annual resource rent, upper bound
TR = total annual revenue from resource extraction
r_i = nominal long-term industrial bond rate

C. Energy Assets: valuation of extracted resource

Valuation of energy assets is done using a combination of the net price method and the present value method, as outlined below.

<u>Stock value calculation -- net price method:</u>

$$RR_{II} = TR - C - \delta$$

$$V = (RR_{II} / Q)\,S$$

$$= [(TR - C - \delta) / Q]\,S$$

$$= [(TR - C) / Q]\,S - (\delta / Q)\,S$$

Assume constant annual extraction: $S / Q = T$ (T is life of reserve)

$$V = [(TR - C) / Q]\,S - \delta T$$

Assume produced capital has the same life as the reserve: $\delta T = K$

$$V = [(TR - C) / Q]\,S - K$$

<u>Stock value calculation -- present value method:</u>

$$PV = \sum_{t=1}^{T} \frac{1/T}{(1 + r_g)^t} \{ [(TR - C) / Q] S - K \}$$

Valuation of extracted resource:

$$RR_A = PV (Q / S)$$

Definition of Symbols:

δ	=	depreciation of produced capital stock
C	=	annual non-capital extraction costs
K	=	produced capital stock value
PV	=	present value of resource stock
Q	=	annual quantity of resource extracted
RR_{II}	=	annual resource rent
RR_A	=	annual resource rent as used in thesis
S	=	stock of remaining reserve
T	=	life of reserve
TR	=	total annual revenue from resource extraction
V	=	net price value of resource stock
r_g	=	real provincial government bond rate
t	=	current year

APPENDIX 2: EDP DATA

	Fig 4 Data: Forest Sector			Fig.6 Data: Energy Sector			Fig.5 Data: Alta. Economy		
Year	Forest GDP	Forest NDP	Forest EDP (Net Depl'ns)	Energy GDP	Energy NDP	Energy EDP (Deple-tions)	Alta. GDP	Alta. NDP	Alta. EDP (For. & En. Depl'ns)
1961							17,856	14,734	13,677
1962							19,131	15,761	14,679
1963							20,207	16,659	15,370
1964							21,233	17,476	16,037
1965							22,783	18,856	17,589
1966							24,587	20,483	19,084
1967							25,166	20,957	19,427
1968							26,534	22,217	20,597
1969							27,970	23,457	21,643
1970							29,121	24,423	22,255
1971	360	294	526	5,107	4,183	1,783	30,244	24,988	22,515
1972	424	351	607	5,860	4,852	1,984	32,665	27,089	24,081
1973	498	418	729	7,355	6,175	1,710	35,741	30,433	25,698
1974	488	416	741	9,812	8,360	2,238	36,319	30,389	24,353
1975	435	375	581	11,016	9,501	2,925	38,793	33,378	26,397
1976	445	382	529	11,204	9,631	2,819	40,924	34,963	27,410
1977	486	417	550	13,294	11,417	3,973	43,510	37,647	30,505
1978	538	462	664	13,362	11,479	3,129	47,557	41,280	32,574
1979	544	470	574	16,113	13,912	4,191	53,456	45,472	35,519
1980	490	421	399	18,253	15,676	4,420	56,451	47,717	36,335
1981	561	479	438	17,515	14,962	3,649	59,743	50,966	40,490
1982	404	344	357	18,433	15,690	4,851	57,616	49,261	39,341
1983	435	369	405	19,911	16,868	2,878	56,405	49,183	35,104
1984	483	408	463	21,625	18,273	4,252	58,669	50,835	36,986
1985	473	398	425	21,821	18,344	5,048	60,140	51,755	38,127
1986	578	470	507	13,169	10,718	3,445	60,095	49,734	42,986
1987	701	576	697	13,898	11,427	4,061	62,376	52,010	44,839
1988	835	695	806	11,780	9,808	4,244	67,242	56,037	51,008
1989	853	709	739	11,483	9,536	3,806	67,325	55,610	49,714
1990	895	743	796	13,093	10,869	3,622	66,807	55,800	48,312
1991	792	652	644	10,560	8,685	4,395	66,449	53,988	49,944
1992	874	714	732	11,544	9,436	4,089	67,772	55,016	49,378
1993	1,152	942	1,003	13,037	10,662	3,719	73,693	59,693	52,599
1994	1,577	1,285	1,301	13,597	11,081	3,999	77,688	62,994	55,392
1995	2,112	1,724	1,209	12,816	10,461	4,341	80,559	65,118	57,975
1996	1,811	1,480	1,460	16,478	13,466	4,163	82,401	66,793	56,886
1997	1,853	1,528	1,468	17,207	14,181	4,810	89,578	72,462	62,544

Sources: GDP, NDP: Alberta Treasury (1990...1999)
Natural Capital Depletion: Statistics Canada (2000)